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Editor: J. C. HUNSAKER, *Massachusetts Institute of Technology*

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VOLUME 1 APRIL, 1934 NUMBER 2

JOURNAL OF THE AERONAUTICAL SCIENCES

Volume 1 APRIL, 1934 Number 2

Flying Boats for Transoceanic Service

W. W. WEBSTER AND W. D. CLARK, *Bureau of Aeronautics, Navy Department*

(Received November 1, 1933)

(*Note.*—The opinions and assertions contained herein are the private ones of the writers and are not to be construed as official or reflecting the views of the Navy Department.)

ALTHOUGH in two instances aircraft had succeeded in crossing the Atlantic prior to the feat of Charles Lindbergh, it remained for that intrepid adventurer alone and unassisted, to launch out over that restless expanse of water, pressing on through the vicissitudes of adverse air and weather conditions to finally set his craft down at his objective, LeBourget, thus completing the first non-stop flight of the Atlantic without mishap.

This accomplishment re-awakened a consciousness of the potentiality of the airplane as a means of rapid transportation over great distances. Innumerable sustained flights have since been carried out but of these only one has been a serious attempt at a solution to the problem of transoceanic transportation by means of a winged vessel large enough for a paying load of passengers with some reasonable provision for comfort. We refer to the noteworthy example of the DO-X. Although beset by numerous misfortunes, this giant boat was the first airplane to succeed in crossing and re-crossing the Atlantic.

Flying boats have been built varying in displacement from 20,000 to 70,000 pounds, but in few cases, so far as known, have these been laid down expressly for passenger transport and long range. It will be recognized, of course, that any commercial venture, especially one requiring a large amount of capital, must give sufficient assurance of good return to warrant the investment.

A factor contributing to delay the advent of successful long range commercial flying boats has been the lack of engines really suitable for the purpose, that is, engines capable of delivering consistently at least 1000 b.hp. and preferably as high as 2000 b.hp. over long periods without breakdown. But as the need becomes apparent it may be assumed that engines of greater horsepower will be forthcoming. This increase in brake horsepower will present difficult problems of propeller design, efficient gearing, low resistance cooling systems and the like.

Those who understand the scope of the work and the practical limitations of the various features, can but wonder at the vision and courage that marked the development of the DO-X. The paucity of suitable engines at the time, alone, was sufficient to discourage any but a hardy pioneer. The discussion of difficulties encountered and means adopted for their solution, together with a wealth of engineering data published by Dr. Dornier are a notable con-

tribution to general knowledge on the subject. His frank discussion of mistakes, as well as successes, is as helpful as it is generous.

With the experience of others to glean from and with some thought given to limiting considerations, we may with due caution venture upon some speculations from the design point of view with the hope that they may be of interest in connection with the further development of long range flying boats. It is noted that two fairly large passenger boats are now under construction in this country but no information is available for publication or comparison at this time.

Requirements

It may be well at the beginning to state the principal governing requirements for long range passenger planes. They are listed as follows:

(a) Clean aerodynamic arrangement of the boat; required for maximum speed and range.
(b) Seaworthiness as a surface vessel; required for take-off and landing in rough water if necessary.
(c) Space available for pay load (passengers) and fuel.
(d) Greatest practicable pay range (result of efficient structural weight design).
(e) Comfort of the passengers.
(f) Operating efficiency.
(g) Safety from fire (stowage of fuel tanks).

Method of Study

It is desirable to explain here that this study is not an attempt to design an airplane as a solution to any particular problem but rather to cover the relative possibilities of various combinations of size and arrangement.

With the above considerations before us it is proposed to examine the problem from the point of view of both biplane and monoplane, as far as possible without preference or prejudice, and to present the results of the analysis for examination. The comparison is based on an analysis of performance of various groups of boats, half of which are biplanes and half monoplanes, the other primary variables being engine power and stalling speed. In order to make the results comparative all boats in each group are geometrically similar, the only difference being in the variation of type of engine used.

From the requirements of lowest possible power plant weight and maintenance cost on the one hand and those of safety and practicable disposition on the other hand, four engines have come to be practically a standard for large boats, particularly monoplanes, and this number is assumed for each airplane of this study but varying in horsepower per unit and type of cooling system as follows:

Series 1—4 air-cooled engines at 800 hp.	3200 hp.
Series 2—4 high temperature liquid honeycomb radiators at 1000 hp.	4000 hp.
Series 3—4 high temperature skin condensers . . . . . 2 at 1000 2 at 2000	6000 hp.

All of these power plants should be available in this country within a year or two. They have been assumed to be supercharged to give the above horsepowers at 6000 feet. In the biplanes a three nacelle arrangement has been chosen with the center engines in tandem. This arrangement seems best adapted to minimum drag of nacelles, combined with minimum loss of power from propeller and cooling difficulties with tandem engines, as well as lending itself to static balance and to the interplane bracing system adopted. In the monoplanes, the engines are disposed two on each side of the hull for reasons that are apparent. The arrangement of the biplane is shown in Fig. 1 and the monoplane in Figs. 2 and 3.

The basic condition assumed for the other primary variable is a stalling speed, $V_s = 65$ miles per hour for the first group of boats (a, b and c). Then with each engine arrangement additional fuel is added to the same boats to give two new groups of boats with $V_s = 67.5$ and 70 miles per hour, respectively, to show the effect on range. In addition several boats are worked out in the 6000 hp. engine series to show the effect of originally designing the structure for $V_s = 70$ m.p.h. and again overloading to give $V_s = 75$ m.p.h. Further, it will be found that the boat sizes will in some cases be sufficiently large to give two decks, one of which may be used for operating and crew's quarters and the other given over to passengers. There seems to be no reason, for purposes of this investigation, to consider any but the biplane of equal span and the full cantilever monoplane. These may be assumed adequately to cover the field of investigation.

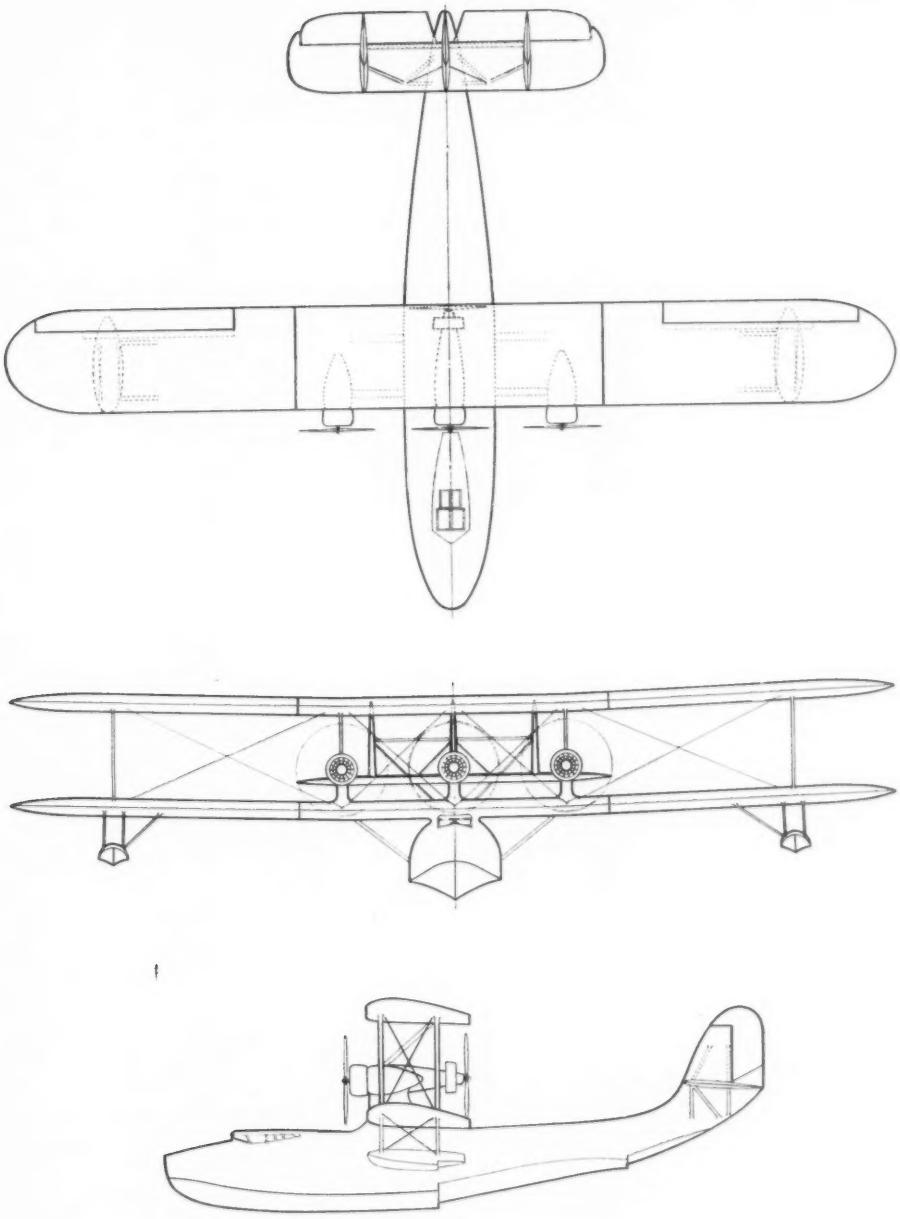

FIG. 1.

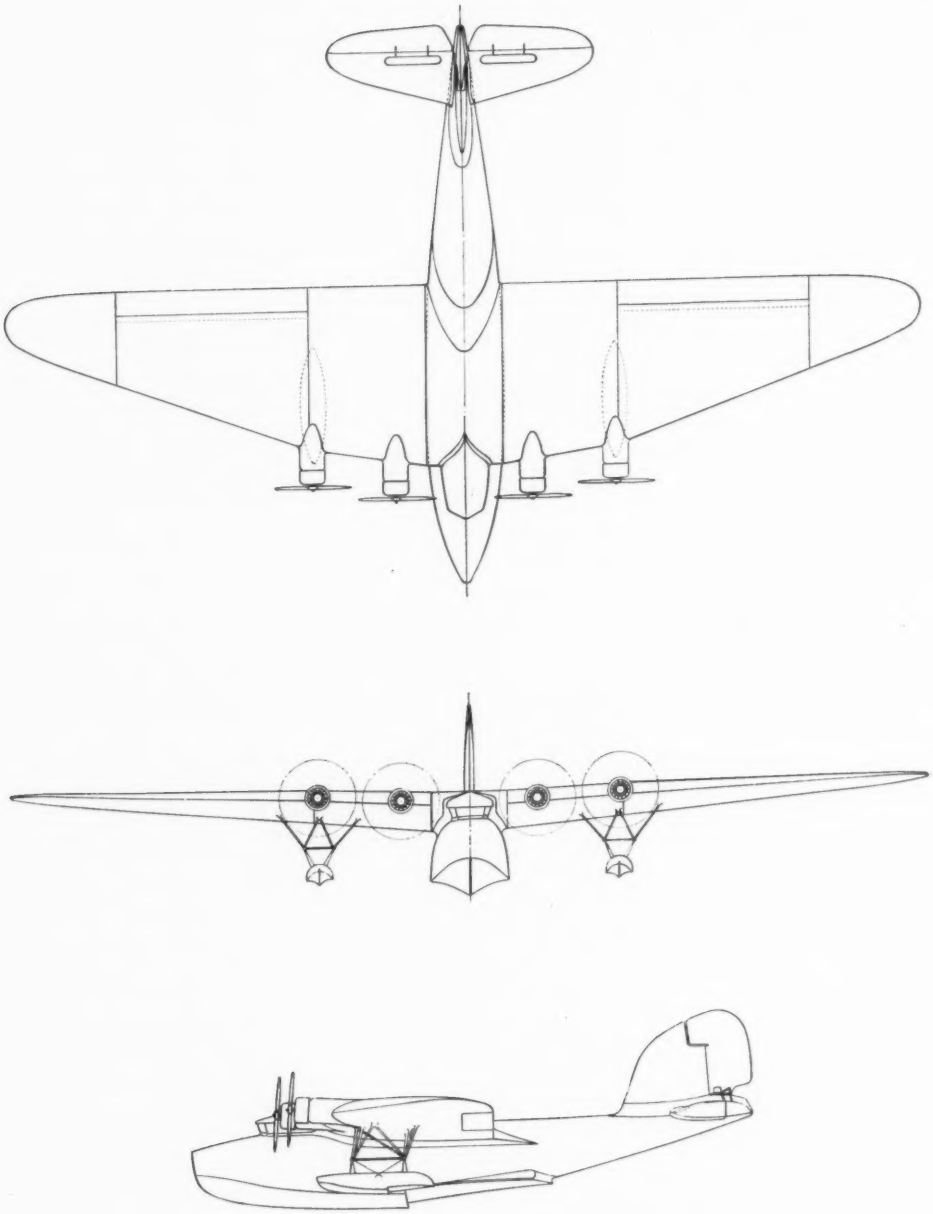

FIG. 2.

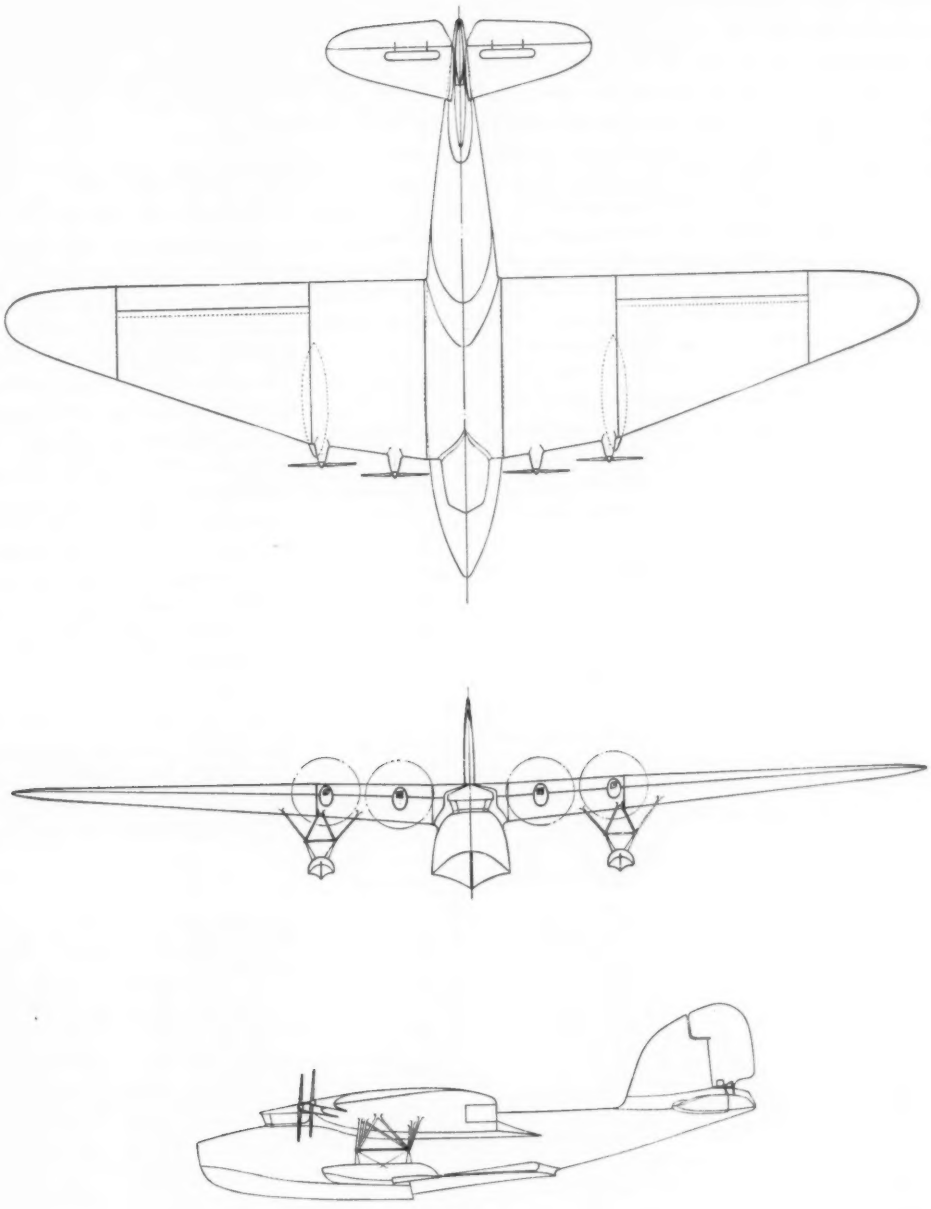

FIG. 3.

Monoplane Design

At this point it is desired to discuss briefly the reasons for the particular arrangement of wing plan form chosen for the monoplane. It will be recognized that usually, in large airplanes, the natural center of gravity of the various structural components comes aft of the aerodynamic center desired, and the engines constitute the counter weight available to move the net center forward to coincide with the aerodynamic center. In many boats the engines are inadequate as a counter weight, and the designer must resort to sweep back, to lengthening the hull forward or increasing the overhang of the engines, or a combination of these devices. Such a procedure is obviously prodigal of weight and should be the last resort. It is necessary to take advantage of any means that can be devised to offset the inevitable upward trend of the structural weight of monoplane wings as they increase in size. An examination of examples of various arrangements of large monoplanes by notable designers fails to disclose any attempt in monoplane wing design to recognize and counteract this except in the case of the Junkers G-38. Here the center section of the wing, the heaviest part, has been moved forward and the engines with it. The effect may be observed in the G-38 in the abnormally short overhang of the fuselage forward. This shortening reduces the weight of the fuselage and appears to be the best means of accomplishing the purpose of obtaining a reduced structural weight. When applied to a flying boat a real saving should be realized in the hull weight. The effect, of course, is sweep back but incorporated to effect only the leading edge. Study will indicate that this does not prevent the torsional forces being adequately cared for in a cantilever structure.

Weight Calculations

The weight of each boat in the first group is arrived at by adopting a unit power loading which is kept constant for all the engine arrangements, the wing areas then being calculated to give the required stalling speed so that the boats in the first group have constant power and wing loadings. Then the unit wing loadings are varied in the other groups of the series while keeping the same wing areas to give the desired comparative stalling speeds, the power loadings being derived automatically.

As previously mentioned three additional special cases are worked out, in two of which the boat is originally designed for $V_s = 70$ m.p.h. and then one of these is overloaded to $V_s = 75$ m.p.h. for comparative purposes. All of this will be clear from an inspection of Table I.

Some comment is probably required as to the reasons for selecting the particular basic power loading of 15 pounds/hp., which goes up to over 17 pounds/hp. in the overload cases. These figures are really a compromise between the conflicting demands of long range and high speed.

TABLE I. COMPARATIVE BOAT ANALYSIS.

WEIGHTS

	PLANE	HP/RPM @ 6000 FT	WING AREA	GROSS WT	#/HP	#/SQ FT	SPAN FT	WING STR	TAIL WT	HULL	AUXILIARY FLOAT	NACELLE	POWER PLANT	MOORING TOWING & HANDLING	INSTRUMENTS	SURFACE CONTROLS	FURNISHING	ELECT WIRE & BAT	CREW	PAY LOAD	RADIO	NAVIG EQUIP	MISCELL EQUIP	TOTAL MINUS FUEL & OIL & 6-30 STEAMS	TOTAL WT LESS FUEL & 6-30 STEAMS	FUEL	OIL	FUEL for 6-30 STEAMS	TOTAL DEADLOAD	TOTAL USEFUL LOAD	%USEFUL LOAD
BIPLANE	a	3200/2400 GEARED 3:2	3071	48000			116.5	6270	980	4800	425	750	6100	530		350	1270	530	1000	8600			2190	34300	13700	12120	480	1100	23205	24795	51.7
	b	4000/3400 GEARED 3:2	3839	60000	15	15.63	130.2	8060	1250	6240	570	1260	7600	670		440	1560	670	1200	10600			2690	43215	16785	14836	595	1355	29675	30325	50.5
	c	6000/5400 GEARED 2:1	5758	90000			159.5	12670	1975	9930	970	1640	11460	1000		660	2300	1000	1400	16000			3975	65485	24515	21660	870	1985	45690	44310	49.3
	d	3200/3400 GEARED 3:2	3071	51770			116.5	6270	980	4800	425	750	6100	530		350	1270	530	1000	8600			2190	34300	17470	15440	615	1415	23520	28250	54.5
	e	4000/3400 GEARED 3:2	3839	64720	16.18	16.858	130.2	8060	1250	6240	570	1260	7600	670	100	440	1560	670	1200	10600	345	60	2690	43215	21505	19015	760	1730	30050	34670	53.6
	f	6000/5400 GEARED 2:1	5758	97070			189.5	12670	1975	9930	970	1640	11460	1000		660	2300	1000	1400	16000			3975	65485	31585	27820	1120	2545	46250	50820	52.4
	g	3200/3400 GEARED 3:2	3071	55680			116.5	6270	980	4800	425	750	6100	530		350	1270	530	1000	8600			2190	34300	21380	18900	760	1720	23825	31855	57.2
	h	4000/3400 GEARED 3:2	3839	69600	17.4	18.13	130.2	8060	1250	6240	570	1260	7600	670		440	1560	670	1200	10600			2690	43215	26385	23330	930	2125	30445	39155	56.2
	i	6000/5400 GEARED 2:1	5758	104390			159.5	12670	1975	9930	970	1640	11460	1000		660	2300	1000	1400	16000			3975	65485	38905	34370	1375	3155	46865	57525	55.0
	u	6000/1400 GEARED 2:1	4964	90000	15	18.13	148.1	10760	1670	8360	800	1640	11460	1000		570	1850	860	1200	12800			3200	56675	33325	29450	1180	2695	41765	48235	53.6
	v	6000/1400 GEARED 2:1	5352	97040	16.18	18.13	153.7	11730	1810	8150	850	1640	11460	1000		610	1850	930	1200	12800			3200	58765	38275	33840	1350	3085	44255	52785	54.3
	w	6000/1400 GEARED 2:1	4964	103300	17.22	20.81	148.1	10760	1670	8360	800	1640	11460	1000		570	1850	860	1200	12800			3200	56675	46625	41220	1640	3765	42635	60465	58.5
MONOPLANE	k	3200/2400 GEARED 3:2	2913	48000			142.8	7310	1090	6200	675	600	6115	505		330	1270	505	1000	8600			2190	36895	11105	9815	392	898	25598	22402	46.7
	l	4000/3400 GEARED 3:2	3641	60000	15	16.48	159.6	9580	1440	7960	900	800	8115	630		420	1560	630	1200	10600			2690	47030	12970	11460	458	1052	33167	26833	44.7
	m	6000/5400 GEARED 2:1	5461	90000			195.5	15550	2450	12750	1830	1000	12280	950		630	2300	950	1400	16000			3975	72270	17730	15670	628	1432	51922	38078	42.3
	n	3200/3400 GEARED 3:2	2913	51765			142.8	7310	1090	6200	675	600	6115	505		330	1270	505	1000	8600			2190	36895	14870	13150	525	1195	25595	25870	50.0
	o	4000/3400 GEARED 3:2	3641	64700	16.18	17.77	159.6	9580	1440	7960	900	800	8115	630	100	420	1560	630	1200	10600	345	60	2690	47030	17670	15620	625	1425	33360	31140	48.1
	p	6000/3400 GEARED 2:1	5461	97040			195.5	15550	2450	12750	1530	1000	12280	950		630	2300	950	1400	16000			3975	72270	24770	21900	875	1995	52485	44585	45.9
	r	3200/3400 GEARED 3:2	2913	55670			142.8	7310	1090	6200	675	600	6115	505		330	1270	505	1000	8600			2190	36895	18775	16590	665	1520	26220	29450	52.9
	s	4000/3400 GEARED 3:2	3641	69380	17.4	19.11	159.6	9580	1440	7960	900	800	8115	630		420	1560	630	1200	10600			2690	47030	22350	19925	798	1830	33965	35415	51.2
	t	6000/3400 GEARED 2:1	5461	104360			195.5	15550	2450	12750	1530	1000	12280	950		630	2300	950	1400	16000			3975	72270	32090	28360	1135	2595	53085	51275	49.2
	x	6000/5400 GEARED 2:1	4710	90000	15	19.11	181.6	15000	2025	10700	1260	1000	12280	950		540	1850	820	1200	12800			3200	62130	27870	24630	985	2255	46760	43220	48.0
	y	6000/5400 GEARED 2:1	5078	97040	16.18	19.11	188.5	14220	2220	11670	1388	1000	12280	950		580	1850	880	1200	12800			3200	64740	32300	28540	1140	2620	49765	47275	48.7
	z	6000/3400 GEARED 2:1	4710	103340	17.22	21.94	181.6	15000	2025	10700	1260	1000	12280	950		540	1850	820	1200	12800			3200	62130	41210	36430	1455	3325	47850	55490	53.6

By using considerably higher power loadings or wing loadings or both, as has been done in some foreign boats, considerably higher ranges might be obtained, but at the expense of speed and also of reasonable take-off and landing speeds. It is felt that a boat designed for transoceanic service should be able to land in the open sea and take-off in unsheltered harbors if necessary, and the growing pressure for higher speed transportation cannot be neglected.

The remaining columns of weights in Table I are derived from the best data available and will probably be subject to considerable criticism, especially the wing and hull weights. However, it is felt that by careful design and by taking advantage of the general arrangement already proposed, they can be met.

For comparative purposes the number of passengers in each of the regular groups of boats is assumed to be 43, 53 and 80, respectively, for the three sizes, whether biplane or monoplane, these numbers being the maximum number which it is believed can be accommodated in the biplane hull arrangement. In the special boats the number of passengers has been decreased from 80 to 64.

Example

The procedure of a typical case is as follows:

With W./hp. = 15 pounds we have for boat "a" 3200 hp. × 15 pounds = 48,000 pounds. Assuming Ky max. = 0.0037 for the biplane wing group the unit wing loading required for $V_s = 65$, is $(65)^2 \times 0.0037 = 15.63$ pounds/sq. ft. Wing area required is 48,000/15.63 = 3071 sq. ft. Assuming an aspect ratio for each wing equal to 8.5 which may be taken as the upper limit for practical considerations, and applying an increase in basic area for rounded tips equal to 4 percent, or $3071 \times 1.04 = 3194$ sq. ft., then span = $(3194 \times 8.5) = 116.5$ ft., with chord = $3194/(116.5 \times 2) = 13.71$ ft.

Tail surface areas are computed by a standard method and in percentage of wing area are horizontal = 12.5 percent and vertical = 9.2 percent, so that $3071 \times 0.125 = 384$ sq. ft. and $3071 \times 0.092 = 282$ sq. ft., respectively. Total tail surface then is $384 + 282 = 666$ sq. ft.

Assuming a known type of hull of 40,600 pounds submerged displacement and a tail length of 23.2 ft., which expressed in terms of wing chord is 3.2, the new hull displacement may be found by using the relation above in terms of the new wing chord or $3.2 \times 13.71 = 43.8$ ft. This gives a constant of $43.8/23.2 = 1.89$; or $(1.89)^3 = 6.75$ and displacement = $40{,}600 \times 6.75 = 274{,}000$ pounds. Similarly the displacement of the wing tip floats work out at 9180 pounds.

The number of passengers that can be conveniently accommodated in a boat of this size is assumed to be 43, which at 200 pounds per passenger gives 8600 pounds.

With 43 passengers and crew, a unit weight for each is allowed to cover life preservers, first aid and medicine, food and water, of 45.625 pounds or $48 \times 45.625 = 2190$ pounds.

The furnishings allowed for are seats 720 pounds, toilets 250 pounds, galley 125 pounds, baggage compartment 75 pounds, fire extinguishing system 100 pounds, giving a total of 1270 pounds.

The fuel, oil and systems are taken at 6.788 pounds per gallon of fuel made up as follows: gasoline at 6 pounds, oil at 0.24 pound, fuel system 0.5 pound and oil system 0.048 pound. Engines amount to 4690 pounds, accessories 360 pounds, engine controls 50 pounds, propellers 800 pounds, starting systems 200 pounds, giving a total of 6100 pounds.

The structural weights for this boat are then computed as indicated in Table I, the total weight less fuel, oil and fuel and oil systems being 34,300 pounds.

Fuel, oil and systems then = 48,000 − 34,300 = 13,700 pounds, or fuel = 12,120 pounds, oil = 480 pounds, fuel system = 1005 pounds, and oil system = 95 pounds, giving a total of 13,700 pounds. Each of the boats has been treated similarly.

Performance Calculations

Calculations of performance were then made in each case by standard methods and are given in Table II. The method of computing range is derived from Brequet's formula as given in Diehl's *Engineering Aerodynamics*, or *N.A.C.A. Tech. Report No. 234*, except that more recent fuel consumption data have been used.

The specific fuel consumption, C_0 for supercharged engines at maximum speed at 6000 feet

TABLE II. COMPARATIVE BOAT ANALYSIS.

	PLANE	GROSS LOAD LBS.	FUEL LOAD LBS.	HP / R.P.M. AT 6000 FT.	#/HP	#/□'	STALLING SPEED MILES/HR	PERFORMANCE: HIGH SPEED AT 6000 FT. MILES/HR.	ABSOLUTE CEILING FEET	ENDURANCE HIGH SPEED HOURS	RANGE HIGH SPEED MILES	ENDURANCE ECONOMICAL SPEED HOURS	RANGE ECONOMICAL SPEED MILES	MAX. L/D	AVG. PROP EFF. %	ORDER OF MERIT: RANGE ECONOMICAL SPEED	HOURS ENDURANCE ECONOMICAL SPEED	ABSOLUTE CEILING	RANGE HIGH SPEED	HOURS ENDURANCE HIGH SPEED	HIGH SPEED
BIPLANE	a	48000	12120	3200/2400 GEARED 3:2	15.0	15.63	65.0	150.2	16800	6.41	975	15.5	1510	10.9	77.5	9	9	2	9	9	5
	b	60000	14835	4000/2400 GEARED 3:2				151.1	16700	7.26	1110	16.2	1580	11.0	77.0	8	7	3	8	7	4
	c	90000	21660	6000/2400 GEARED 2:1				155.3	17400	7.08	1113	16.1	1585	11.4	78.0	7	8	①	7	8	①
	d	51770	15440	3200/2400 GEARED 3:2	16.18	16.86	67.5	148.6	15100	8.16	1235	18.7	1850	10.9	77.5	6	6	5	6	6	7
	e	64720	19015	4000/2400 GEARED 3:2				149.5	15000	9.32	1420	19.8	1960	11.0	77.0	5	5	6	5	4	6
	f	97070	27920	6000/2400 GEARED 2:1				153.7	15800	9.12	1425	19.9	1990	11.4	78.0	4	4	4	4	5	2
	g	55680	18900	3200/2400 GEARED 3:2	17.4	18.13	70.0	147.0	13400	10.00	1505	21.7	2180	10.9	77.5	3	3	8	3	3	9
	h	69600	23330	4000/2400 GEARED 3:2				147.9	13300	11.44	1730	23.1	2320	11.0	77.0	2	2	9	2	①	8
	i	104390	34370	6000/2400 GEARED 2:1				152.1	14100	11.23	1745	23.2	2360	11.4	78.0	①	①	7	①	2	3
	u	90000	29450	6000/2400 GEARED 2:1	15.0	18.13	70.0	162.0	16500	9.62	1585	22.2	2290	11.4	78.5	3	3	①	3	3	①
	v	97040	33830	6000/2400 GEARED 2:1	16.18	18.13	70.0	156.9	15200	11.02	1760	24.3	2470	11.4	78.0	2	2	2	2	2	3
	w	103300	41220	6000/2400 GEARED 2:1	17.22	20.81	75.0	158.2	13400	13.47	2190	28.0	2970	11.4	78.0	①	①	3	①	①	2
MONOPLANE	k	48000	9815	3200/2400 GEARED 3:2	15.0	16.48	65.0	158.4	19700	5.19	829	13.6	1360	12.6	79.0	6	7	2	9	8	6
	l	60000	11460	4000/2400 GEARED 3:2				159.7	19700	5.62	904	13.5	1360	12.8	78.5	6	8	2	7	7	4
	m	90000	15670	6000/2400 GEARED 2:1				163.7	20400	5.12	844	12.6	1275	13.2	79.5	7	9	①	8	9	①
	n	51765	13150	3200/2400 GEARED 3:2	16.18	17.77	67.5	157.3	18000	6.96	1106	17.6	1780	12.6	79.0	4	5	4	6	6	8
	o	64700	15620	4000/2400 GEARED 3:2				158.7	18000	7.66	1227	17.8	1810	12.8	78.5	3	4	4	4	4	5
	p	97040	21900	6000/2400 GEARED 2:1				162.6	18700	7.16	1176	16.9	1740	13.2	79.5	5	6	3	5	5	2
	r	55670	16590	3200/2400 GEARED 3:2	17.4	19.11	70.0	156.0	16400	8.77	1390	21.1	2170	12.6	79.0	2	2	6	3	3	9
	s	69580	19925	4000/2400 GEARED 3:2				157.4	16400	9.86	1560	21.6	2240	12.8	78.5	①	①	6	①	①	7
	t	104360	28360	6000/2400 GEARED 2:1				161.3	17000	9.27	1516	20.8	2170	13.2	79.5	2	3	5	2	2	3
	x	90000	24630	6000/2400 GEARED 2:1	15.0	19.11	70.0	171.4	19200	8.05	1395	20.0	2120	13.2	80.0	3	3	①	3	3	①
	y	97040	28540	6000/2400 GEARED 2:1	16.18	19.11	70.0	166.2	18100	9.31	1567	22.2	2330	13.2	79.5	2	2	2	2	2	3
	z	103340	36430	6000/2400 GEARED 2:1	17.22	21.94	75.0	168.4	16200	11.90	2040	27.2	2960	13.2	79.5	①	①	3	①	①	2

is assumed to be 0.51 for liquid-cooled and 0.59 for air-cooled engines.

The maximum L/D is arrived at by the summation of parasite drag and the application of curves of aspect ratio.

Range and endurance calculations were made for the two ends of the speed scale only, i.e., maximum and economical speed. This should be sufficient for comparative purposes and avoids argument as to the most desirable cruising speed. Anyone interested in ranges at any intermediate speeds can readily work out his own data. It is evident of course that there are a great number of other possible distributions as between passenger and fuel loads if one is interested in carrying fewer passengers for longer distances.

The most interesting performance data in Table II are plotted in Figs. 4 to 8 for clearer comparison.

There was also plotted an arbitrary factor of pay load times range divided by gross load as a measure of load efficiency, but it was evident that the pay loads of each series of boats had been selected or kept in such a close ratio to the ranges that the results were practically identical, except for the special boats, with Fig. 7 (range at economical speed), which may therefore be used to indicate the actual pay load carrying efficiency of the various boats.

Method of General Performance Comparison

In Fig. 9 is plotted an arbitrary factor or figure of merit for the various boats, which may have some value in comparing their overall or composite performance as passenger carrying vehicles. This is obtained by multiplying together the figures for pay load, range and economical speed, dividing by a multiple of the gross weight. The performance figures in the numerator cover the three essential features of such a plane, i.e., it carries so much, so far, so fast. The use of a multiple of the gross weight as a denominator is probably more arbitrary. It was not desired to enter into any detailed discussion of costs per passenger mile, etc., although it is fully realized that the ultimate commercial value of any study must finally be reduced to such terms. However, if we assume that the gross of first cost, operating cost and overhead is roughly proportional to gross weight, inspection will show that the factor presented is actually an equivalent of the reciprocal figure to cost per

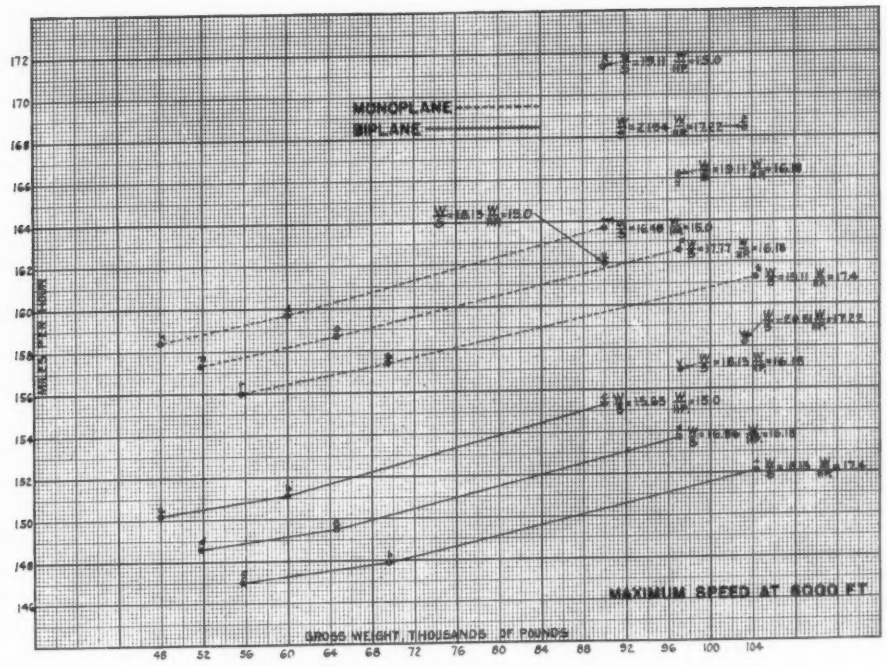
MONOPLANE
BIPLANE
MAXIMUM SPEED AT 6000 FT
MILES PER HOUR
GROSS WEIGHT, THOUSANDS OF POUNDS
172
170
168
166
164
162
160
158
156
154
152
150
148
146
48
52
56
60
64
68
72
76
80
84
88
92
96
100
104

FIG. 4.

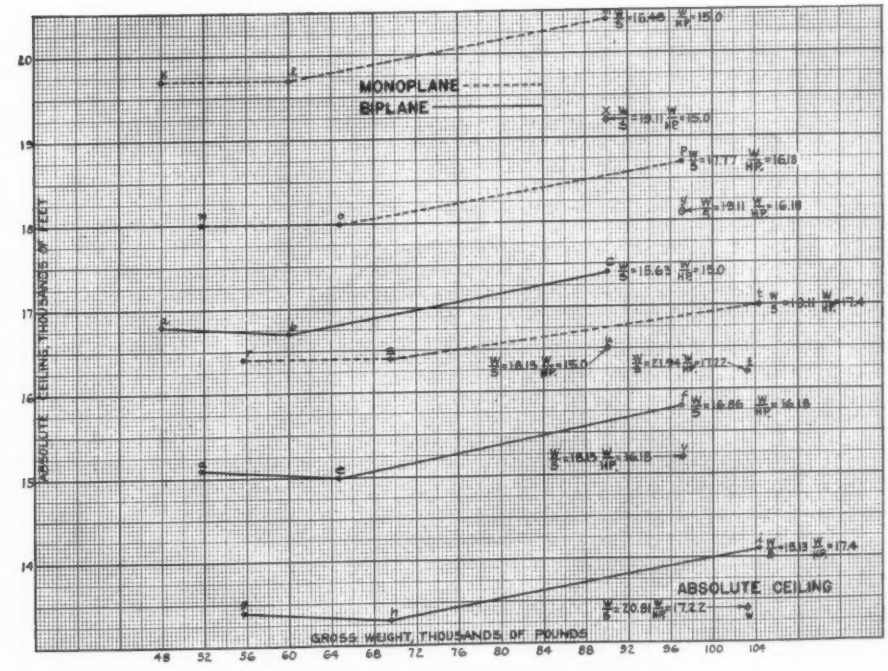
MONOPLANE
BIPLANE
ABSOLUTE CEILING
ABSOLUTE CEILING, THOUSANDS OF FEET
GROSS WEIGHT, THOUSANDS OF POUNDS
20
19
18
17
16
15
14
48
52
56
60
64
68
72
76
80
84
88
92
96
100
104

FIG. 5.

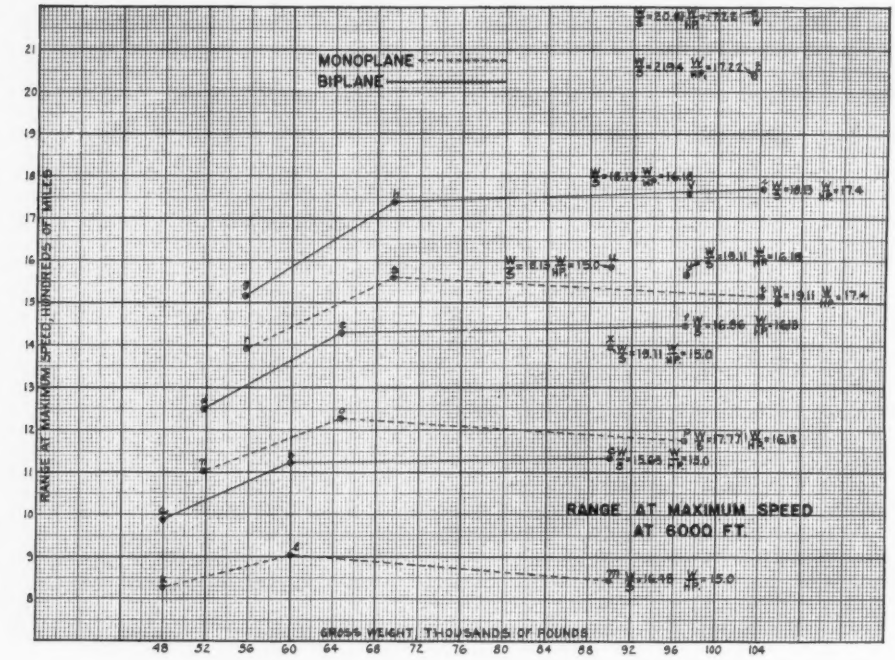
MONOPLANE
BIPLANE
RANGE AT MAXIMUM SPEED, HUNDREDS OF MILES
GROSS WEIGHT, THOUSANDS OF POUNDS
RANGE AT MAXIMUM SPEED
AT 6000 FT.

FIG. 6.

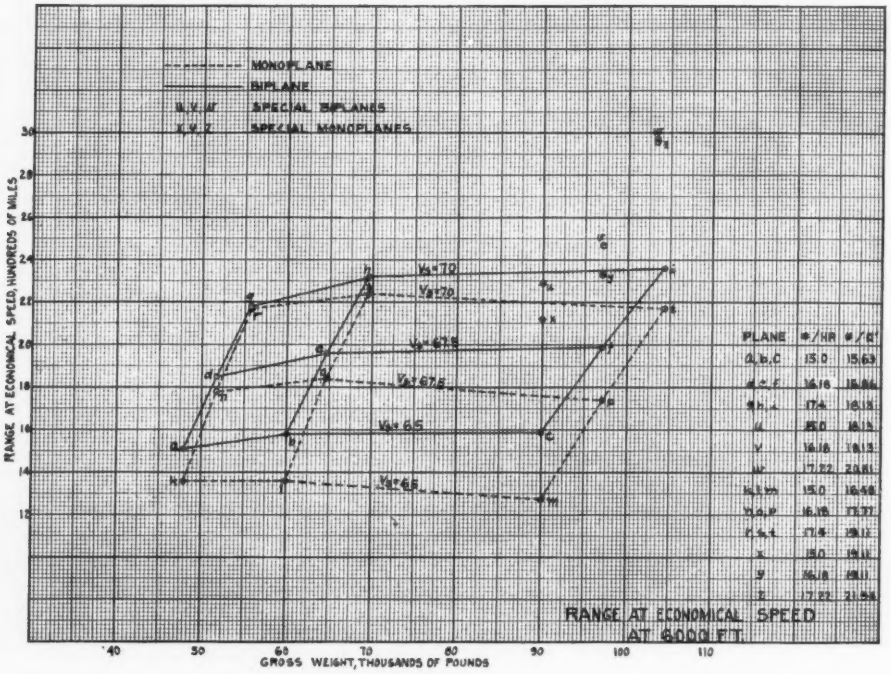
MONOPLANE
BIPLANE
R, V, W SPECIAL BIPLANES
X, Y, Z SPECIAL MONOPLANES
RANGE AT ECONOMICAL SPEED, HUNDREDS OF MILES
GROSS WEIGHT, THOUSANDS OF POUNDS
RANGE AT ECONOMICAL SPEED
AT 6000 FT.

FIG. 7.

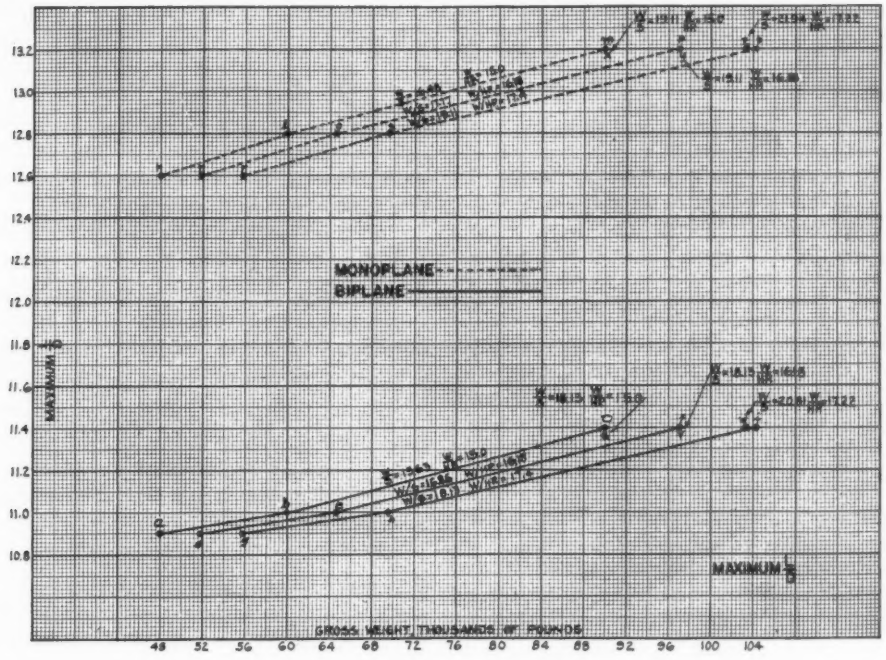
MONOPLANE
BIPLANE
MAXIMUM
GROSS WEIGHT THOUSANDS OF POUNDS

FIG. 8.

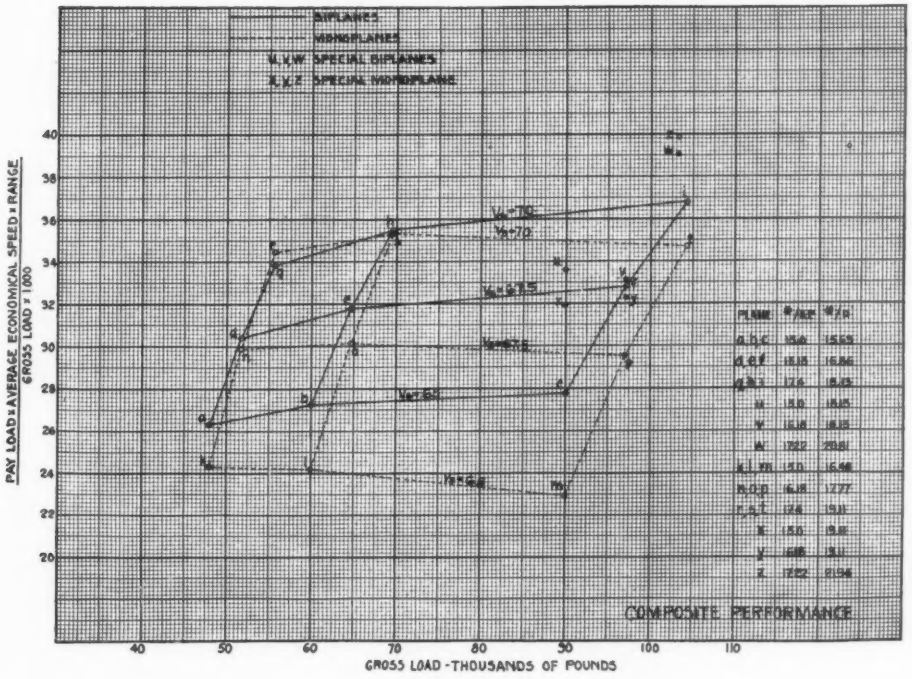
BIPLANES
MONOPLANES
U,V,W SPECIAL BIPLANES
X,Y,Z SPECIAL MONOPLANE
PAY LOAD = AVERAGE ECONOMICAL SPEED = RANGE
GROSS LOAD = 1000
COMPOSITE PERFORMANCE
GROSS LOAD - THOUSANDS OF POUNDS

FIG. 9.

passenger mile with the additional element of speed introduced. In other words, we have an engineering factor equivalent to the usual terms of evaluating commercial efficiency.

Conclusions

In view of the foregoing, it is obviously too ambitious an undertaking to draw from the data and charts developed herein any definite conclusions applicable to any particular problem. It is felt that the principal value of this study is probably to indicate a fairly simple but at the same time comprehensive method of attacking such problems leaving to the reader who is particularly interested freedom to make his own deductions.

However, there are three or four general conclusions which appear to be indicated, some of which are probably already more or less obvious and generally accepted:

First, the monoplane is superior to the biplane for speed, but is inferior in range or load carrying efficiency and also in composite performance in the range of gross loads and stalling speeds usually considered for transoceanic service. The monoplane is apparently more efficient only when the wing loading is comparatively high (roughly corresponding to about 70 m.p.h. stalling speed in sizes around 50,000 pounds gross weight or about 80 m.p.h. in sizes around 100,000 pounds).

Second, with increases in actual size, as limited by the four-engine power plants considered available, maximum speed increases steadily, but appreciable increases in range or load carrying efficiency apparently are not obtained above about 60,000 to 70,000 pounds gross weight and in the monoplane range actually decreases above this size. The composite performance is naturally a compromise between speed and range. Of course the above considerations neglect the advantages of additional room and airworthiness for passenger comfort, which features come with increased size and may govern actual size for this type of service.

Third, although there is some decrease in speed resulting from overloading to higher stalling speeds there is obviously a great increase in range and composite performance figures to be obtained, limited of course by practical consideration of take-off and landing conditions which may be encountered. Decreased load factors are the penalty of this method.

Fourth, on the other hand, if a boat is designed for a higher stalling speed in the beginning, appreciably increased speed and range are obtained, but, because of decreased pay load, the composite efficiency remains about the same.

Finally, it is fairly evident that transoceanic boats carrying a large number of passengers over a safe nonstop distance of 3000 miles are within the realm of practicability at the present state of the art only by resorting to extremely large sizes and extremely high stalling speeds. The development of a large Diesel engine with a specific fuel consumption of about 0.40 lb./hp./hour would place an entirely different aspect on the situation and, in addition to the safety feature involved, appears definitely called for as the one step which would do more than any other to advance transoceanic air travel on a practical paying basis.

Turbulence, Companion of Reynolds Number*

HUGH L. DRYDEN, *U. S. Bureau of Standards*
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INTRODUCTION

THE conditions under which the results of measurements of the aerodynamic forces on small models held at rest in wind tunnels can be safely used to forecast the corresponding forces on full size aircraft moving through the air are of interest to every aeronautical engineer. For some purposes it is sufficient to assume that the aerodynamic forces are proportional to the density of the air, the square of the relative air speed, and the area of cross section of the model, the factor of proportionality depending only on the shape and attitude. It was early recognized, however, that this simple relation does not accurately describe the facts. The variation of the factor of proportionality, or coefficient as it is generally termed, with size is called "scale effect" and it is now known that the scale effect is but a specialized aspect of the effect of the Reynolds number, the name given to the product of linear dimension times speed divided by the kinematic viscosity. Coefficients determined from wind tunnel tests cannot be applied to full scale aircraft without correction unless the wind tunnel tests are made at the Reynolds number of the full scale aircraft. This is not feasible in most cases, but special wind tunnels[1, 2] have been constructed for the study of the effect of Reynolds number over a wide range.

Another condition to be fulfilled in wind tunnel testing is that the relative motion between the air and the model must be the same as that between the full scale aircraft and the air. For purposes of design the full scale aircraft is assumed to move forward at a uniform speed into still air. Hence the artificial wind in the wind tunnel must be uniform and steady in speed and direction. This condition can be secured only approximately. There are always present small ripples or fluctuations which do not usually exceed a few percent of the average speed. It has long been known[3, 4] that the presence of these small fluctuations, collectively called turbulence, has a considerable effect on the resistance of spheres and cylinders within a certain range of Reynolds numbers. The resistance of airship models[5] was also shown to be sensitive to turbulence, and the designers of airships learned to distrust all wind tunnel measurements of the drag of airships. The designer of airplanes has not hitherto been disturbed either by the troubles of the experimenter studying the resistance of spheres and other objects of no practical interest or by the troubles of the comparatively few designers of airships. The problem became of more interest to him with the demonstration[6] that the effects of turbulence on the maximum lift coefficients of airplane wings are of the same or greater order of magnitude than the effects of Reynolds number.

As a matter of fact, it is becoming increasingly clear that in aerodynamic problems we have to deal with a new independent variable whose

* Publication approved by the Director of the Bureau of Standards of the U. S. Department of Commerce.

[1] Max M. Munk and Elton W. Miller, *The Varitable Density Wind Tunnel of the National Advisory Commitee for Aeronautics*, T.R. No. 227, N.A.C.A., 1926.

[2] Eastman N. Jacobs and Ira H. Abbott, *The N.A.C.A. Variable-Density Wind Tunnel*, T.R. No. 416, N.A.C.A., 1932.

[3] David L. Bacon and Elliott G. Reid, *The Resistance of Spheres in Wind Tunnels and in Air*, T.R. No. 185, N.A.C.A., 1923.

[4] H. L. Dryden and R. H. Heald, *Investigation of Turbulence in Wind Tunnels by a Study of the Flow about Cylinders*, T.R. No. 231, N.A.C.A., 1925.

[5] H. L. Dryden and A. M. Kuethe, *Effect of Turbulence in Wind Tunnel Measurements*, T.R. No. 342, N.A.C.A., 1930.

[6] C. B. Millikan and A. L. Klein, *The Effect of Turbulence. An Investigation of Maximum Lift Coefficient and Turbulence in Wind Tunnels and in Flight*. Aircraft Engineering, August, 1933, p. 169.

effects are widespread, of considerable magnitude in many cases of interest, and of an importance at least equal to the effects of the Reynolds number. Moreover, it appears that the effects of Reynolds number and of turbulence are the expression of one basic phenomenon. Hence the title; *Turbulence, Companion of Reynolds Number.* It is the purpose of this paper to give a general picture of the present status of the problem of turbulence as it appears to one working in this field.

What is Turbulence?

The word turbulence is used in a rather vague sense to mean any departure from the condition of uniform and steady flow. Generally, variations of the mean speed or mean direction of flow from place to place, for example across the working section of a wind tunnel, are not regarded as turbulence. Thus more specifically, turbulence connotes fluctuations with time; the speed at any point fluctuates from instant to instant about a mean value. The comparatively slow fluctuations which can be detected by ordinary measuring instruments are not included in the concept of turbulence; the frequencies included are those above a rather indeterminate limit of one or more per second.

The concept of turbulence as analogous to ripples in the smooth stream is helpful as a concrete picture, if one is required. The photographs of Ahlborn[7] also stir the imagination. It is difficult to believe, at first, that any significant effects could be produced by doubling or halving the magnitude of small ripples which are only a few percent of the mean speed, but such is the case.

Various distinctions are made based on the phase relations between the several components of the speed at a given point or between the same components at different points. For example, the fluctuations in speed may be periodic, the period but not necessarily the phase being the same in all parts of the flow. Such is the case in the Kármán vortex street behind a cylinder or in the vortex system behind an airfoil section. In such cases we have to do with an ordered turbulence. The flow may be described by a system of discrete vortices and it would perhaps be better to speak of this type of motion as vortex motion.

At large Reynolds numbers vortex motion passes over into a type of motion known as fully-developed turbulence or, preferably, eddying flow. In this type of motion, the fluctuations are not periodic and there is no constant phase relation between the fluctuations at different places. There are average relations between the phases of the fluctuations of the several components of the velocity at any given point, so that there is a transport of momentum from one layer of the fluid to another, giving rise to tangential forces between the layers.

The turbulence with which we are mainly concerned in this paper is that present in the air streams found in wind tunnels. The fluctuations are not periodic, their amplitude is generally small, and they do not appear to give rise to tangential forces. Hence the fluctuations are believed to be random fluctuations. The mean amplitude is constant across the core of the air stream, i.e., that part not influenced by wall friction.

It is unfortunate that the same word is used without qualification for so many distinct concepts. Occasionally, the distinction is made by the adjective "initial" for the turbulence present as a characteristic of the air stream and "fully-developed" for that characteristic of the flow behind objects placed in the stream; but for the most part, one must depend on the context for the distinction. In this paper, the word "turbulence" is used hereafter to denote the initial turbulence characteristic of the air stream. The "fully-developed" turbulence will be designated "eddying flow."

How is Turbulence Measured?

The concept of turbulence as a general term to denote fluctuations of the speed is not sufficiently definite to be satisfactory. In particular, this concept does not offer a method for giving numerical values to the turbulence in different wind tunnels; for fluctuations may occur in each of the three components of the speed, the wave form may undergo all conceivable variations, and the magnitude of the fluctuations may vary

[7] Fr. Ahlborn, *Turbulenz und Mechanismus des Widerstandes an Kugeln und Zylindern*, Zeits. f. tech. Physik **12**, 482–491 (1931), Figs. 1 to 5. Translated in T.M. No. 653, N.A.C.A., 1932.

through wide limits. A number of functions may be suggested, whose mean values may or may not be of significance. The choice of function can be intelligently made only if some more or less complete description and theory of the effect of turbulence is available. Such a theory has not been developed, nevertheless two methods of measuring turbulence have been of practical value.

The oldest method for comparing the turbulence of different air streams is by observation of the resistance of spheres. The resistance coefficient,* C_D, has a value of about 0.4 to 0.5 at low Reynolds numbers; in a relatively narrow range of Reynolds number, it falls to about 0.1 which is maintained at high Reynolds numbers. The value of the Reynolds number at which the rapid decrease occurs is a function of the turbulence, the critical Reynolds number decreasing as the turbulence increases.

It has been suggested[5] that this procedure be made quantitative by stating the value of the Reynolds number at which the resistance coefficient is 0.3, i.e., approximately the mean of the values on each side of the critical region. Certain precautions are necessary, namely to arrange the supports at the rear so that they introduce no additional turbulence. Recent developments suggest that it is also necessary to control the roughness of the surface of the sphere and it has been found that the critical Reynolds number defined in this way varies slightly with the diameter of the sphere.[6] At the Bureau of Standards, we have generally used a sphere 8.6 inches in diameter, one of the standard hard rubber bowling balls which is readily obtained.

The second method that has been found useful in correlating experimental data is the direct measurement of one type of mean value of the amplitude of the fluctuations.[8, 9] The equipment consists of a special form of hot-wire anemometer, with a wire of small diameter, an amplifier, an electrical network to compensate for the lag of the wire, and an alternating-current milliammeter. The speed fluctuation is converted into an alternating electric current whose intensity is measured by a thermal type milliammeter. Thus, the square root of the mean square of the departures from the mean value is determined. The turbulence is defined as the ratio of the average fluctuation to the mean speed. If the wave form were sinusoidal, a turbulence of 1 percent would mean fluctuations of ± 1.4 percent from the mean speed. Actually no account is taken of wave form. The equipment is usually designed to pass only frequencies of fluctuation between 10 and 1000 per second, thus excluding comparatively slow changes of speed.

The apparatus for direct measurements of this kind has not yet been developed in simple and portable form and its use has been confined to three or four laboratories. Two of the laboratories[5, 6] have independently compared this method with the sphere method with quite satisfactory results. While much refinement is to be expected, either of these methods gives a suitable basis for the correlation of data on the effect of turbulence on aerodynamic properties as measured in wind tunnels.

Methods of Reducing and Increasing Turbulence

The study of the effects of turbulence proceeds with difficulty unless methods for controlling the magnitude of the turbulence in a given wind tunnel are available. Not many laboratories have access to more than one or two wind tunnels and experiments in wind tunnels of different size always involve other factors in addition to turbulence. The control of turbulence over wide limits without the introduction of other undesired effects such as changes in the uniformity of the mean speed across the working section is a matter of great difficulty. Methods of increasing the turbulence are available but no method is known for reducing the turbulence of an existing turbulent stream.

It is believed that the source of turbulence is the wake of other objects upstream from the model, principally the wake from the honeycomb

* If D is the resistance, d the diameter, V the air speed, ρ the air density, A the area of cross section $\pi d^2/4$, q the velocity pressure $\frac{1}{2}\rho V^2$, then the resistance coefficient $C_D = D/Aq$.

[8] H. L. Dryden and A. M. Kuethe, *The Measurement of Fluctuations of Air Speed by the Hot-Wire Anemometer*, T.R. No. 320, N.A.C.A., 1929.

[9] W. C. Mock, Jr., and H. L. Dryden, *Improved Apparatus for the Measurement of Fluctuations of Air Speed in Turbulent Flow*, T.R. No. 448, N.A.C.A., 1932.

cell walls. Thus the effect of turbulence is in a certain sense an interference effect, present because the models are tested in the wake of other objects. In some closed return tunnels, it has been suggested that the model is tested in its own wake. Honeycombs are usually necessary to avoid intermittent large eddies, but they introduce small ones which diffuse rapidly over the cross section. At a moderate distance, the source may be ignored and the turbulence considered as uniformly distributed, a characteristic of the air stream striking the model. The magnitude of the fluctuations slowly decreases with increasing distance from the honeycomb.

Wind tunnels without a honeycomb or guide vanes usually show a small inherent turbulence, which is intermittently increased by large amounts as large eddies pass through. Measurements of properties sensitive to turbulence are almost impossible under such circumstances.

The known method[10] of securing a small turbulence is to use a large area reduction in the entrance cone (4 or 5 to 1) and to place the honeycomb at the large end as far from the working section as possible. The design of the honeycomb is of secondary importance. By such a design of the entrance, the turbulence may be reduced below one percent (critical Reynolds number for sphere, 210,000). With further refinements to secure as smooth a flow as possible in all parts of the circuit, using honeycombs or straightening vanes which produce as little disturbance as possible, values below 0.5 percent have been obtained.[11] (Critical Reynolds number for sphere 260,000.)

With a tunnel of small turbulence to begin with, the obvious method of increasing the turbulence is by the installation of a honeycomb near the working section. In a large wind tunnel, it is not convenient to use this method because of the great care and consequent length of time necessary to install the honeycomb. Unless the installation is carefully made, the distribution of mean speed across the working section will not be satisfactory. Moreover, unless a rigid construction is used, the honeycomb will shift and alter the calibration of the tunnel. Here is a problem of wind tunnel design awaiting solution.

A simple wire screen is often used instead of a honeycomb. With either screen or honeycomb, the maximum turbulence obtainable with a satisfactorily uniform distribution of mean speed is of the order of two to three percent. (Critical Reynolds number for sphere 120,000 to 140,000.)

If instead of a wire screen, a grid of cylindrical rods $\frac{1}{8}$ inch or $\frac{1}{4}$ inch in diameter is used, a larger turbulence may be secured at the expense of introducing well marked variations of mean speed behind the individual bars. At the Bureau of Standards we have had some success by the use of a $\frac{1}{2}$ inch mesh screen to which small aluminum tags about $1\frac{1}{4}$ inches by 1 inch by $\frac{1}{32}$ inch were fastened by paper clips. The tags, fluttering in the wind, produce a large uniformly distributed turbulence and the mean speed is quite uniform. The tags wear rapidly at high wind speeds and must be frequently replaced. The small eddies produced by either of these methods are rapidly damped and the magnitude of the turbulence falls off rapidly with increasing distance. Variation of the distance provides a convenient control of the magnitude, but the models are always subject to a turbulence whose magnitude varies along the stream. Values of the turbulence up to 5.5 percent (critical Reynolds number for sphere not determined) have been obtained by this method.

There is room for much additional work on methods for control of turbulence. It is highly important to be able to vary the turbulence through wide limits; otherwise experience shows that faulty conclusions may be drawn, the data being too limited.

Turbulence of the Atmosphere

It was stated previously that for purposes of design the full scale aircraft was considered to move forward into still air, in which case the turbulence would by definition be zero. When one remembers however the almost constant presence of winds which continually change in speed and direction, this assumption is seen to

[10] Hugh L. Dryden, *Reduction of Turbulence in Wind Tunnels*, T.R. No. 392, N.A.C.A., 1931.

[11] C. B. Millikan and A. L. Klein, *Description and Calibration of 10-foot Wind Tunnel at California Institute of Technology*, Trans. A.S.M.E., Aeronautical Engineering, 1932–33.

require examination. There have been as yet few experimental studies of the turbulence of the free atmosphere. One must of course distinguish the fine-grained, comparatively high frequency fluctuations here designated turbulence from the well-known gustiness of comparatively long period. The most significant experiments are those of Millikan and Klein[6] which point strongly to a very small turbulence in the atmosphere. Some unpublished experiments at the Bureau of Standards with the hot-wire equipment show fairly large fluctuations of comparatively low frequency (10 per second or less) at comparatively low elevations in the wake of houses and trees on higher ground about a mile away. Fluctuations of higher frequency comparable to those found in wind tunnels were also present, but their amplitude was small. Confirmatory experiments should be made in other parts of the country in all kinds of weather, but it seems likely that aircraft flying through the air meet little turbulence of the type found in wind tunnels.

The Basic Effect of Turbulence

Having considered the new aerodynamic variable, turbulence, the methods used for varying its magnitude and for measuring it, and its probable value in the atmosphere as compared with values found in wind tunnels, we turn to the effects of this variable on aerodynamic properties. It is believed, but not yet completely proved, that all observed effects of turbulence are due to one basic phenomenon, namely, the effect of turbulence on the transition from laminar to eddying flow in the boundary layer. This basic phenomenon is studied most clearly in the flow near a thin flat plate with sharp symmetrical leading edge, the plate being set parallel to the air flow (skin friction plate). When the distribution of mean speed is measured near such a plate in an air stream adjusted to have nearly zero pressure gradient, it is found that the flow for some distance from the leading edge corresponds to that derived theoretically by Blasius from Prandtl's equations for laminar flow in a boundary layer.[12, 13] At a distance from the leading edge corresponding to a constant value of the Reynolds number formed from this distance and the speed of the free air stream, the flow begins to depart from the Blasius distribution and after a rather long transition region obeys the empirical laws for eddying flow, derived from observations on eddying flow in pipes. So long as the turbulence of the air stream is unchanged, the transition occurs at a fixed value of the Reynolds number formed from the distance to the leading edge and the speed of the free air stream. If, however, the turbulence is increased, the critical Reynolds number is decreased and *vice versa*. There is thus a functional relation between this critical Reynolds number and the turbulence of the air stream, which could be, but has not yet been, experimentally determined. Some unpublished experiments at the Bureau of Standards give two sets of values, namely, Reynolds number 1,100,000 for turbulence of 0.5 percent and Reynolds number 100,000 for turbulence of 3 percent.

The effect of a pressure gradient in the air stream is to modify the shape of the distribution curves in the laminar flow, as well as to change the critical Reynolds number for a given turbulence. It has been suggested that if a Reynolds number be formed from some suitably defined thickness of the boundary layer, and the speed at the outer edge of the boundary layer, the relation between this Reynolds number and turbulence will be independent of the magnitude of the pressure gradient. This has not been proven, but some unpublished experiments at the Bureau of Standards indicate that at least for small pressure gradients, it is approximately true. The values obtained for this Reynolds number, R_δ, formed from the "reduced" thickness* of the boundary layer are as follows:

Velocity Distribution in the Boundary Layer Along a Plane Surface, Thesis, Delft, 1924.

[12] M. Hansen, *Die Geschwindigkeitsverteilung in der Grenzschicht an einer eingetauchten Platte*, Abh. Aerodyn. Inst. Aachen, No. 8, 31–45 (1928). Translated in T.M. No. 585, N.A.C.A., 1930.

* The reduced thickness δ is defined by

$$\delta = (1/U)\int_0^\infty (U-u)dy$$

where u is the speed at the distance y from the plate, and U is the speed of the free air stream.

Turbulence 0.5 percent, $R_\delta = 1900$; turbulence 3.0 percent, $R_\delta = 580$.

The boundary layers near bodies other than skin friction plates are subjected to the influence of large pressure gradients arising from the approximately potential flow around them. The boundary layer equations of Prandtl may be used to compute the flow in the boundary layer as long as the flow remains laminar. However a transition to eddying flow occurs, and it is assumed, but not fully proven, that the transition occurs at a value of R_δ which depends only on the turbulence of the air stream striking the body. This is the basic phenomenon, which is believed to be capable of explaining all of the observed effects of turbulence.

Classification of Effects Observed and Expected

The basic effect of turbulence which has just been described can be observed experimentally only with considerable difficulty. A special technique is required and the labor is very great. More often the experimental observations are not so detailed, and only an integrated result, say the total force, is measured. Under such circumstances, we may make a classification of the effects of turbulence on the basis of the way in which they are encountered in wind tunnel measurements, as follows:

(1) Effect on frictional forces
(2) Effect on separation
    a. Drag of spheres and cylinders
    b. Maximum lift of airfoils
(3) Free boundary layer effects on form drag
(4) Effects on diffusion
(5) Miscellaneous effects

1. Effect on frictional forces

When the flow in the boundary layer is eddying, the skin friction is many times greater than when the flow is laminar. Hence an increase of turbulence, producing earlier transition, increases the skin friction. This effect has been prominent mainly in measurements of the drag of airship models.[5, 14] It is also found in experiments on skin friction on plane surfaces.[12] It is to be expected that the effect will be found in the measurements of the profile drag of airfoil sections whose form drag is small, although we do not at present know of any experiments along this line.

2. Effect on separation. a. Drag of spheres and cylinders

When the pressure outside the boundary layer increases in the downstream direction, the layer thickens rapidly. The fluid particles near the wall are dragged along by the friction of the neighboring faster moving particles but are retarded by the pressure. As the layer thickens, the retarding effect becomes predominant and finally causes a reversal of the flow. The reversal of flow, on account of the consequent accumulation of fluid, separates the flow from the surface. This happens even when the flow in the boundary layer is laminar. The onset of eddying flow modifies the process. In the eddying flow there is a more thorough mixing of the air particles, and the driving action of the outer layers on the inner layers (near the surface of the body) is greater. The air in the boundary layer is thus enabled to flow farther against an adverse pressure gradient and the process of separation is delayed.

At low values of the Reynolds number of a sphere or cylinder, the flow in the boundary layer is laminar and separation takes place in a manner governed by the laws of laminar flow, namely at a definite location dependent on the shape but not on the Reynolds number. As the Reynolds number is increased, the Reynolds number formed from the thickness of the boundary layer and the speed at the outer edge reaches the value at which eddying flow begins at some point upstream from the laminar separation point. Separation is then delayed, the wake is smaller and the form resistance is decreased. The skin friction is such a small part of the total drag that the increased skin friction is negligible.

If the turbulence of the air stream is increased, the transition occurs at a lower Reynolds number and hence the critical Reynolds number of the sphere or cylinder is reduced. The relation between the critical Reynolds number of a sphere and the turbulence of the air stream has been determined, as mentioned previously.

[14] Hilda M. Lyon, *Effect of Turbulence on Drag of Airship Models*, Reports and Memoranda No. 1511, British Aero. Res. Comm., 1932.

3. Effect on separation. b. Maximum lift of airfoils

A study has recently been made of the effect of turbulence on the maximum lift on one airfoil[6] and the results have been explained on the basis of an interplay between the laminar separation point and the point of transition similar to that outlined for the sphere, except that here separation means low lift, no separation high lift. On this one airfoil the effect of turbulence was to increase the maximum lift coefficient. Experiments have been published[15] which show that for other sections the effect of turbulence is to decrease the maximum lift coefficient. It remains to be shown that this reversal in sign of the effect can be explained as an interplay between laminar separation point and point of transition at different angles of attack; in other words that the same reasoning which led to increased lift coefficients for one shape of section will lead to decreased lift coefficients for another shape of section.

The magnitude of the effect was quite large for the section on which tests were made, namely N.A.C.A. 2412. Increasing the turbulence from 0.4 percent to 2.8 percent at a Reynolds number of 1,500,000 increased the maximum lift 31 percent.

4. Free boundary layer effects on form drag

One of the most interesting and unexpected effects of turbulence is that observed by Linke[16] on the drag of cylinders at comparatively low Reynolds numbers. Linke's experiments showed that a laminar boundary layer could exist as a free laminar layer following separation and that as the free layer thickened, transition to eddying flow finally occurred. This transition was affected by the turbulence of the air stream.

The transition of the free layer makes itself evident in a modification of the pressure on the rear of the cylinder. As the speed is increased, the point of transition approaches the cylinder, the eddying free layer sweeps away the "stagnant" fluid more readily, and decreases the pressure at the rear more than in proportion to the increased velocity pressure. Hence the drag coefficient rises, a phenomenon that has always been somewhat of a puzzle.[17] When the turbulence of the wind tunnel stream is increased, the transition occurs earlier and the rise in coefficient occurs earlier.

When the transition point reaches the cylinder, separation and transition occur simultaneously through a wide range of Reynolds number, as indicated by the constant drag coefficient.

5. Effects on diffusion

The flow of heat from hot surfaces is greatly dependent on whether the flow near the surface is laminar or eddying and hence effects of turbulence of the stream are to be expected. We do not know of any systematic experiments on the effect of initial turbulence on heat flow.

It is to be expected that the lateral diffusion of smoke or the diffusion of heat from a small heated object would be affected by the initial turbulence of the air stream. Thus the temperature distribution downstream from a hot wire should be a function of the turbulence.

6. Miscellaneous effects

The rate of rotation of Robinson cup anemometers has been observed[18] to be a function of the turbulence of the air stream. A bead around the rim of the cups decreases greatly both the variation of the rate with turbulence and with Reynolds number.

Some unpublished data at the Bureau of Standards indicate that the force on thin flat plates normal to the wind is a function of the turbulence. An increase in turbulence from 0.7 to 2.3 percent gave an increase in force coefficient of 4 percent. This is one of the few cases in which there is an effect of turbulence where there is no effect of Reynolds number.

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[15] John Stack, *Tests in the Variable Density Wind Tunnel to Investigate the Effects of Scale and Turbulence on Airfoil Characteristics*, T.N. No. 364, N.A.C.A., 1931.

[16] W. Linke, *Neue Messungen zur Aerodynamik des Zylinders, insbesondere seines reinen Reibungswiderstandes*, Phys. Zeits. **32**, 900 (1931).

[17] L. Bairstow, *Variation with Speed of the Forces due to Viscosity*, Reports and Memoranda No. 100, Brit. Adv. Comm. Aero., 1913–14.

[18] Hugh L. Dryden, W. C. Mock, Jr., and G. B. Schubauer, *The Effect of Turbulence on the Rating of Cup Anemometers*, Phys. Rev. **43**, 1042A (1933).

The Relation Between the Effects of Turbulence and of Reynolds Number

It appears that the effect of turbulence and of Reynolds number are related, in that each is the manifestation of changes occurring in the flow in the boundary layer. Either an increase in Reynolds number or an increase in turbulence will cause the transition to occur closer to the point of origin of the layer at the front stagnation point, and in this sense the effects of increased turbulence and increased Reynolds number are equivalent. In general, if increased Reynolds number causes an increase in the coefficient, then increased turbulence also causes an increase in the coefficient; if increased Reynolds number causes a decrease in the coefficient, then increased turbulence causes a decrease in the coefficient.[15] There is some evidence that there may be cases in which there is no effect of Reynolds number but some effect of turbulence.[15] In these cases the effect of increased turbulence is to increase the coefficient.

This relation between the two effects apparently leads to the conclusion that it would be advantageous to make wind tunnel tests in a stream of large turbulence. This conclusion is to the best of our present knowledge unwarranted. While the qualitative relations hold with some exceptions, it seems impossible to establish a quantitative relation. For example, in Millikan and Klein's study of the maximum lift of airfoils,[6] maximum lift coefficients obtained with large turbulence were much higher than those obtainable at any Reynolds number with small turbulence. The appearance of the curves is such that no quantitative equivalence can be established between increased turbulence and increased Reynolds number. The interrelations between laminar separation point as determined by shape and angle, and transition point as determined by turbulence and Reynolds number are so involved, as already pointed out, that the same basic phenomenon can probably lead to effects of opposite signs.

As another illustration of the impossibility of establishing a quantitative correspondence of the two effects, one may examine the two analyses which have been given for the effect of turbulence on airship models.[6, 19] A detailed study of either analysis will show that even the qualitative relationship does not hold throughout; in Fig. 15 of reference 4 for example, at Reynolds numbers from 10^5 to 5×10^5, increasing the Reynolds number decreases the drag coefficient whereas increasing the turbulence increases the coefficient. Hence we must conclude that the relationship between the two effects is far from simple although each is an expression of changes in the boundary layer flow.

Unsolved Problems

The preceding discussion has been sprinkled with unsolved problems. The most fundamental and most important is the clarification of what has been called the basic effect. Why does the transition occur and what characteristic of the fluctuations, if any single characteristic is effective, determines the transition? What are the effects of frequency, wave form, and average spatial dimensions of the individual molar particles? It is known for example that fluctuations with frequencies of the order of one per second or slower have little or no effect, yet a fair correlation can be established between average amplitude and aerodynamic effect, with no regard to frequency. What is the explanation of this puzzle?

A second basic problem is whether any single function of the fluctuating components can be correlated exactly with the several effects listed in the previous classification. Will sphere measurements give a better correlation with the effects of turbulence on separation than hot-wire measurements of mean amplitude of fluctuation?

A third unsolved problem is whether the single basic effect is sufficient to explain all of the diverse types of aerodynamic effects observed. For example, can one and the same basic effect explain both increased and decreased lift coefficients on airfoils differing only in shape.

A final important problem is the effect, if any, of turbulence on the standard Pitot-static tubes used for the measurement of mean speed. For if there is any appreciable effect, the status of

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[19] Clark B. Millikan, *The Boundary Layer and Skin Friction for a Figure of Revolution*, Trans. A.S.M.E., Applied Mechanics, 1932. A P M–54–3.

all measurements is in doubt. We have found at the Bureau of Standards that the comparison between the readings of a vane type anemometer (wind-mill with axis parallel to wind) and a standard Pitot-static tube is unaffected by varying the turbulence between 0.5 and 2.5 percent. This proves only that if there is an effect, it is the same for both instruments; but because of the very different types involved, it is believed that the result means no effect on either instrument. In contrast with this result, the ratio between the force on a flat plate of aspect ratio 6 placed normal to the wind and the velocity pressure as determined by the standard Pitot-static tube varies, and the variation is interpreted as an effect of turbulence on the force on a flat plate. It will be apparent that it is very difficult to be certain that there is no effect of turbulence on the Pitot-static tube. Those who recall the experiments of Kumbruch[20] should be reminded that the large eddies introduced by him are of a different magnitude than the small fine grained turbulence which concerns us here. All wind tunnel practice is based on the assumption that the Pitot-static tube is unaffected by turbulence.

[20] H. Kumbruch, *Messung strömender Luft mittels Staugeräten.* Forschungsarbeiten Gebiete Ingenieurwesens, No. 240, 1921. Translated in T.M. No. 303, N.A.C.A., 1925.

Economic Speed of Air Liners

F. M. Green, *Armstrong Siddeley Motors, Ltd.*

(Received December 12, 1933)

AIR travel must be fast; but there is a wide divergence of speed at which air liners are operated in various parts of the world. In Europe the usual cruising speed is about 100 miles per hour; but this is being increased gradually. In America 150 miles per hour has been adopted as general practice on aircraft of recent manufacture. 200 miles an hour is achieved on aircraft intended to be mail carriers only. In this memorandum an attempt is made to find what speed of operation is most profitable for a passenger air liner irrespective of the convenience of the passengers in saving time.

Since the results of this analysis depend largely on assumptions which are based on personal experience of design they apply only to aircraft of about 20,000 lb. gross weight. Aircraft much larger or much smaller need special consideration. The errors involved in applying the results to aircraft from 1500 to 25,000 lb. gross weight will be small.

Basis of Comparison

The usefulness of an air liner depends on the profits that can be earned in a year compared with its first cost. It is assumed that the cost of an aircraft is proportional to its gross weight; also that all the hypothetical aircraft we shall consider are designed to the same standard of excellence as regards comfort, safety and sound construction.

Earning Capacity of an Air Liner

It is obvious that the earning capacity of an air liner per hour is proportional to the net pay load multiplied by the cruising speed. If all aircraft fly the same number of hours in a year then the earning capacity per year is proportional to the same figure. It is true that faster aircraft will make more stops in a day than slower aircraft if the length of the stage is the same, and will therefore waste more time on the ground. Against this, the faster aircraft will lose less time against head winds, and this will probably compensate for the wasted time. It is obvious that time on the ground should be reduced to a minimum and that all aerodromes should have the best possible equipment for refuelling.

Cost of Running

It is a fortunate coincidence that in England at any rate the cost of aircraft structure and of engines is almost exactly the same on a basis of weight. The cost of a complete air liner is

therefore proportional to its weight irrespective of the size of engines used. Capital charges, including obsolescence, depreciation and insurance depend on first cost and consequently on weight, and running expenses depend very largely on the same figure. It is true that engine upkeep per unit of weight is higher than for aircraft structure, and that we may expect that air liners with a low weight per horsepower will be more expensive to run than those with a higher ratio. The analysis will show that the most economic speed is obtained with aircraft with the minimum horsepower weight ratio that will satisfy other conditions; consequently the economic speed is not affected by this consideration. The larger engined aircraft also use more fuel per mile at a higher speed and again they should be debited with this cost, but this is also neglected for the same reasons, as the optimum point in the final curve is not affected.

Broadly then, we may assume that the cost of operation per hour of an airliner is proportional to its weight, with a reservation that aircraft with low weight horsepower ratios are a little worse than those with minimum horsepower.

Factor of Usefulness

From the previous considerations it is possible, as a first approximation, to express the commercial value of an air liner in relative terms by multiplying the percentage net pay load by the speed of operation. This gives a figure which I propose to call "the factor of usefulness." If the speed is measured in miles per hour and the aircraft weight in tons, then the gross weight of the aircraft multiplied by its factor of usefulness gives the earning capacity in ton miles of pay load per hour. The air liner with the highest factor will be the most profitable, neglecting cost of fuel.

Method of Analysis

The method I have used is to make a series of assumptions based on what I believe to be the best contemporary practice. I have then calculated the percentage pay load for an aircraft designed to cruise at speeds from 100 to 170 miles per hour. I have assumed that change of horsepower does not alter the drag of the aircraft, which is in favor of the high powered air liner. Against this, I have made no allowance for the reduction of drag due to the smaller cabin if fewer passengers are carried, but this is in favor of the lower powered machine. It is also assumed that the efficiency of propulsion is the same.

Design Assumptions

(1) Range in still air is constant, and is 500 miles.
(2) Net pay load includes crew and special passenger equipment.
(3) An allowance of 25 percent of the net pay load is added for passenger equipment.
(4) Wing loading is 15 lb. per sq. foot for a monoplane of fairly high lift coefficient. This is present day British practice, but is lower than current American practice.
(5) Span loading = gross weight/span^2 = 2.5.
(6) Parasite drag at 100 m.p.h. = 25 lb. per 1000 lb. gross weight. This applies to an unbraced monoplane with retracted undercarriage.
(7) Structure weight = 42 percent gross weight.
(8) Crew and their equipment, including wireless = 4 percent gross weight.
(9) Motor units complete with starting gear, fairing, silencer, airscrews, piping and oil cooler = 2.5 lb. per declared hp.
(Note:—Declared "horsepower" means the maximum horsepower for 50 hour runs at normal speed, and not the maximum horsepower that can be obtained. British type test horsepower is usually 12 percent less than is possible for a run of one hour's duration.)
(10) Fuel and oil at cruising power = 0.54 lb. per bhp./hour.
Tanks for fuel and oil = 0.06 lb. per bhp./hour.
Total of fuel, oil and tanks = 0.60 lb. per bhp./hour.
(11) Propulsive efficiency of airscrews = 75 percent.
(12) Cruising horsepower must not exceed 75 percent of declared horsepower.

Analysis

The analysis showed that if considerations of power for take-off were neglected then the most economical speed was 115 m.p.h. The gross power required for the air liner was only 48 hp. per 1000 lb. weight, and this is too low for a safe take-off. In my experience the lowest safe horsepower is about 62 hp. per 1000 lb. weight. This gives not only a reasonable take-off and rate of climb for an aircraft loaded 15 lb. per sq. foot of surface, but enables a 4-engined aircraft to fly easily at a safe height with one engine stopped. By taking this horsepower as a minimum, the most economic speed becomes 130 m.p.h., at which speed the factor of usefulness is 29, compared with 30 at 115 m.p.h. that would

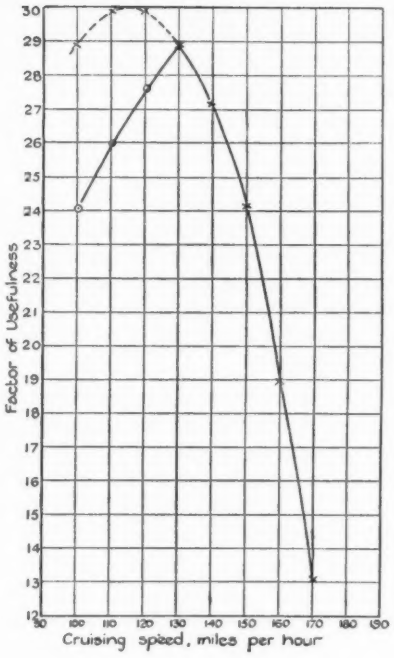

FIG. 1.

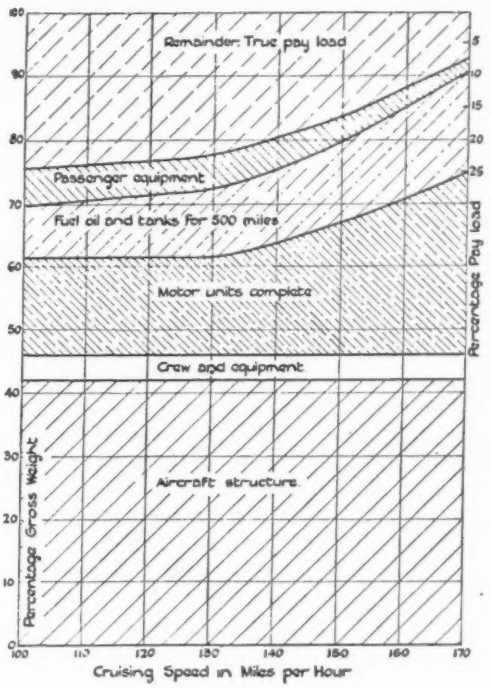

FIG. 2.

be obtained if the lower horsepower had been safe. On the other hand, the factor at 115 m.p.h. with a minimum of 62 hp. per 1000 lb. drops to 26.5. This is shown in Fig. 1 which gives the factors for cruising speeds from 100 to 170 m.p.h. The dotted line is the factor with what I consider an unsafe margin of horsepower.

Fig. 2 shows the way in which the gross weight of the aircraft is divided into its various components, assuming a minimum of 62 hp. per 1000 lb. weight.

INFLUENCE OF HEIGHT

The analysis has been made for flight in air of standard density. The best speed at altitude will be increased in proportion to the cube root of the density ratio until the engines are working at full throttle and are giving 75 percent of their declared ground horsepower. This will occur at a height of about 7500 feet, when the economic speed will be increased from 130 to 140 miles per hour, and the factor of usefulness will become 31.3 instead of 29.

CONCLUSION

On the basis of the best current practice in aircraft design, my conclusion is that the most profitable aircraft is one on which the horsepower is the minimum for safe take-off and flying with one engine stopped if a multi-engined machine. Further, that the best cruising speed for this aircraft is that obtained by running the engines at the greatest power at which experience determines that they are reliable in service and at which they do not suffer abnormal wear. This speed is likely to be 130 m.p.h. at ground level, rising to 140 m.p.h. at 7500 feet.

North American Air Mass Properties[1]

H. C. WILLETT, *Massachusetts Institute of Technology*
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A. INTRODUCTION

IN this discussion the term *air mass* is applied to an extensive portion of the earth's atmosphere which approximates horizontal homogeneity. The formation of an air mass in this sense takes place on the earth's surface wherever the atmosphere remains at rest over an extensive area of uniform surface properties for a sufficiently long time so that the properties of the atmosphere (vertical distribution of temperature and moisture) reach approximate equilibrium with respect to the surface beneath. Such a region on the earth's surface is referred to as a *source region* of air masses. As examples of source regions we might cite the uniformly snow and ice covered northern portion of the continent of North America in winter, or the uniformly warm waters of the Gulf of Mexico and the Caribbean Sea.

The concept of the air mass is of importance not in the source regions alone. Sooner or later a general movement of the air mass from the source region is certain to occur, as one of the large-scale air currents which we find continually moving across the synoptic charts. Because of the great extent of such currents and the conservatism of the air mass properties, it is usually easy to trace the movement of the air mass from day to day, while at the same time any modification of its properties by the new environment can be carefully noted.

Since this modification is not likely to be uniform throughout the entire air mass, it may to a certain degree destroy the horizontal homogeneity of the mass. However, the horizontal differences produced within an air mass in this manner are small and continuous in comparison to the abrupt and discontinuous transition zones, or *fronts*, which mark the boundaries between different air masses. Frontal discontinuities are intensified wherever there is found in the atmosphere a convergent movement of air masses of different properties.

Since the air masses from particular sources are found to possess, at any season, certain characteristic properties which undergo rather definite modification, depending upon the trajectory of the air mass after leaving its source region, the investigation of the characteristic properties of the principal air mass types can be of great assistance to the synoptic meteorologist and forecaster. We owe this modern analytical method of attack on the problems of synoptic meteorology and weather forecasting to the Norwegian School of Meteorologists, notably to J. Bjerknes and T. Bergeron. The analytical study of the synoptic weather map is based essentially on the identification and determination of the movement of air masses and fronts rather than of areas of high and low pressure as the entities of prime significance. The justification of this procedure is evident from the fact that the weather which is experienced in a given region does not depend upon the prevalence of high or low barometric pressure. Even in the same locality a high or a low may be accompanied by widely varying meteorological conditions. The weather in a given locality depends upon the properties of the air mass which is present or upon the interaction which is taking place between two air masses along a front in the near vicinity. The fundamental concept is that of the air mass, for upon the properties and movements of the individual air masses appearing on the map depend not only the weather in the area covered by each air mass but also the formation and intensification of fronts and the genesis, development and movement of lows or disturbances on the fronts. But in order that

[1] An abbreviated discussion of No. 2 in Volume II of *Papers in Physical Oceanography and Meteorology*, published by Massachusetts Institute of Technology and Woods Hole Oceanographic Institution.

the full advantage of a careful analysis of the weather map may be utilized in weather forecasting, it is absolutely necessary that the thermodynamic properties of the air masses (lapse rate and vertical moisture distribution) be approximately known. This is especially true of aviation forecasts, for just the meteorological elements which are of greatest interest to the pilot are those which are dependent upon the air mass properties. For good forecasting of convective turbulence, thunderstorms, horizontal visibility, fog and haze, cloud forms and ceiling, for just such forecasting full knowledge of the air mass properties is essential. Since it rarely happens that the forecaster has available for the current weather map aerological material sufficient for the satisfactory determination of the properties of the air masses present, an investigation of the characteristic properties of the typical American air masses should be of value both for practical weather forecasting and for a better understanding of the physical processes underlying our usual weather sequences. It was with this thought in mind that the paper here under consideration was written. The discussion was definitely restricted to a consideration of the homogeneous air masses individually, the investigation of the whole complicated frontal problem of converging air masses being left for later consideration in the light of more extensive American aerological data.

B. Classification of Air Masses

The study of synoptic weather maps indicates that air masses are entities having such definite characteristic properties that they may be classified and studied as distinct types. Since the characteristic properties of an air mass at any point depend primarily upon the nature of its source region and secondarily upon the modifications of the source properties which the air mass has undergone en route to the point of observation, any classification of air mass types must be based fundamentally on the air mass source regions, with perhaps a sub-classification based on later modifications of the source properties.

The air mass sources fall naturally into two groups, the tropical or sub-tropical, and the polar or sub-polar. The large areas on the earth of uniform surface conditions and comparatively light atmospheric movement lie almost entirely at high latitudes or at low latitudes. In middle latitudes, generally speaking, we find the zone of greatest atmospheric circulation or of most intense interaction between the warm and cold currents, i.e., air masses from the tropical and polar regions. Consequently, in middle latitudes the uniformity of conditions and the light air movement which must characterize a source region are generally lacking. Rather than the development of horizontally homogeneous air masses, we find here the rapid modification, in varied forms, with changing environment, of the characteristic polar and tropical air mass types. Thus the basis of any comprehensive air mass classification must be the distinction between the polar and the tropical source types, with a further distinction between the modified forms which these principal types acquire in middle latitudes during their later life history.

The air mass classification may be carried further by the sub-division of the polar and the tropical source types into continental and maritime groups, according as the source in each case is a continental or an oceanic region. Since the uniform source regions are always entirely continental or entirely maritime and since this is *the essential* difference between source regions in the same latitude, this distinction furnishes a satisfactory basis for a general grouping of the air masses from each latitudinal zone. Consequently, for the investigation of the properties of the air masses which may appear in a given locality, the most significant designation of the different individual polar and tropical air mass types is that based on the particular geographical area within which the air mass has its source. It is, of course, necessary to keep in mind the season of the year when considering the characteristics of any particular geographical source region, as these characteristics, especially in the case of the continental areas, change greatly from the cold to the warm season. It is also necessary to consider the modifications of the original source properties of the air mass types, effects which become more pronounced with the increasing movement of the air mass from the source region. Eventually the properties of the air mass become so fundamentally modified from the source

TABLE I. *Classification of American air masses by geographical source regions.*

Source by Latitude	Source by Nature	Local source region	Corresponding air mass designation	Symbol
Polar (*P*)	Continental	Alaska, Canada and the Arctic	Polar Canadian (Polar continental)	P_c
		Modified in Southern and Central U.S.	Transitional Polar Canadian	N_{pc}
	Maritime	North Pacific Ocean	Polar Pacific	P_p
		Modified in Western and Central U.S.	Transitional Polar Pacific	N_{pp}
		Colder portions of the North Atlantic Ocean	Polar Atlantic	P_a
		Modified over warmer portions of the North Atlantic Ocean	Transitional Polar Atlantic	N_{pa}
Tropical (*T*)	Continental	Southwestern U.S. and Northern Mexico	Tropical continental	T_c
		Modified form of negligible importance	Transitional tropical continental	N_{tc}
	Maritime	Gulf of Mexico and Caribbean Sea	Tropical gulf	T_g
		Modified over the U.S. or the North Atlantic Ocean	Transitional tropical maritime	N_{tm} or N_{tg}
		Sargasso Sea (Middle Atlantic)	Tropical Atlantic	T_a
		Modified over the U.S. or the North Atlantic Ocean	Transitional tropical maritime	N_{tm} or N_{ta}

properties that the mass must be given a special transitional designation.

Table I gives the complete classification of the principal North American air masses by geographical source regions, together with the principal transitional form for each air mass. The ordinary designation and the symbol entered for each air mass in the last two columns are those which appear on the Massachusetts Institute of Technology weather maps.

C. Significance of the Properties of the Principal Air Mass Types

It is impossible in a short review to attempt even a summary of the seasonal properties of all of the air masses listed in Table I. Consequently, this discussion will be restricted to three of the air mass types, P_c, P_p and T_g, and will apply to the winter season only. These three air masses are dominant in determining our winter weather in the United States and it is during the winter season that the air mass contrasts become most significant. Because the air mass contrasts are less pronounced and have been less thoroughly investigated for the summer season than for the winter, it was deemed advisable to limit this discussion to the winter period rather than to the summer period when there is the greatest activity in aviation. Consequently, the following discussion will illustrate the applicability of the analytical method to weather forecasting, without pretending to indicate more than a small fraction of the possibilities met with in actual practice.

In Table II we find tabulated for each of the three principal air masses at two different aerological stations the mean values of the temperature, T, the specific humidity,* w, the relative humidity, $R.H.$, and the equivalent potential temperature, θ_E, at the ground and at the successive km levels above sea level. These mean values are simply the averages of a number

* The quantity w is not quite the specific humidity, defined by $q=0.622e/p$ but the mass ratio of water vapor to dry air, defined approximately by $w=0.622e/(p-e)$ where e and p are water vapor and total atmospheric pressures.

TABLE II. *P_c, P_p and T_g air masses (winter).*

Air mass	Station	Element	Elevation above sea level (km)				
			Surface	1	2	3	4
P_c	Ellendale	T (°C)	−26.1	−25.3	−20.1	−21.5	−25.4
		w (g)	0.32	0.35	0.60	0.50	0.45
		R.H. (percent)	82	80			
		θ_E (°A)	250	256	272	280	288
	Boston	T (°C)	−6.3	−14.3	−18.0	−23.0	−29.0
		w (g)	0.9	0.6	0.5	0.3	0.2
		R.H. (percent)	43	55			
		θ_E (°A)	267.0	268.0	274.3	279.0	283.3
P_p	Seattle	T (°C)	8.3	0.0	−8.3	−14.3	−19.3
		w (g)	4.4	2.7	1.5	0.8	0.4
		R.H. (percent)	75	88			
		θ_E (°A)	292	289	288	289	294
	Ellendale	T (°C)	−1.2	7.0	0.8	−6.5	−14.0
		w (g)	3.0	3.0	2.2	1.5	1.1
		R.H. (percent)	84	40			
		θ_E (°A)	284	299	300	301	302
T_g	Groesbeck	T (°C)	18.8	14.0	13.0	7.5	
		w (g)	12.6	10.4	4.1	1.2	
		R.H. (percent)	90	95	40	15	
		θ_E (°A)	327	326	318	312	
	Boston	T (°C)	14.0	13.7	8.7	2.0	−3.7
		w (g)	8.8	6.5	6.2	4.6	2.9
		R.H. (percent)	82	60	86	84	85
		θ_E (°A)	310	314	319	318	319

of ascents chosen as typical of each air mass type at each station. They represent, therefore, the best observational evaluation which can be made of the so-called characteristic properties of each air mass type. An explanation of the full significance of θ_E cannot be made here[2] but it may be stated in a general way that turbulent mixing of an air stratum tends to effect isothermalcy of θ_E, whereas a rapid vertical change in θ_E indicates marked atmospheric stratification. If θ_E increases with elevation, the possibility of thermal convection in the atmosphere is practically excluded, whereas if θ_E decreases with elevation, the atmosphere is potentially unstable, an instability which becomes actual with sufficient vertical displacement of the affected stratum. Such is the displacement which may occur at a warm front. The amount of displacement necessary to effect actual instability of the affected stratum is less, the higher its relative humidity.

[2] See C. G. Rossby, *Thermodynamics Applied to Air Mass Analysis*, M.I.T. Meteorological Papers, Vol. I, No. 3.

In Table II the first station included for each air mass type is the one which gives the best indication of the characteristic properties of the air mass as it advances directly, fresh from the source region. The second station is chosen to indicate the most important modified form in which the air mass appears during its later history. Thus for the P_c air mass, Ellendale indicates the characteristic cold wave type in the middle west, while Boston indicates the rather fundamentally modified cold wave type in the northeastern United States. For the P_p air mass, Seattle indicates the characteristic properties as the air mass approaches the northwest coast of the United States fresh from the source, while Ellendale indicates the importantly modified form which the air mass assumes by the time it reaches the interior of the continent, the characteristic N_{pp} air mass type. Finally, for the T_g air mass Groesbeck indicates the characteristic properties as the air mass first advances northward from the Gulf of Mexico, while Boston indicates the modified form which the air mass assumes as it moves northeastward, approximating the characteristic N_{tm} (N_{tg}) type.

The P_c air masses

Let us consider now the significance of the characteristic properties of each of the air mass types tabulated in Table II, bearing in mind that the entire discussion applies essentially only to the winter months. The P_c air masses are those which originate over the snow and ice covered regions extending from the interior of Canada northwestward over Alaska and northward into the Arctic. The passage of an air mass of this type over Ellendale marks the advance of the typical cold wave from the Canadian northwest, the characteristic properties of the air mass observed at Ellendale being practically those acquired in the source region. We note at once from Table II the extreme coldness of this air mass at Ellendale but also the fact that the temperature increases above the ground, reaching a maximum at about the $2\frac{1}{2}$ km level. Actually we find that in the early stages of the cold air outbreak when the wind is still moderate to fresh northwest or north from the ground up to high levels, the temperature decreases through the first few hundred meters above the ground. This is a result of the mixing affected by mechanical turbulence. Consequently a minimum temperature is often found just below the 1 km level, with a marked inversion above. In the later stages of the cold air outbreak, as the wind diminishes and becomes very light at the ground, radiational cooling effects a lowering of the air temperature at the ground, while subsidence effects a raising of the temperature at upper levels. Thus, with the possible exception of a shallow turbulence layer near the ground, the P_c air mass shows very marked stability through the lower 2 km, usually even a rather large temperature inversion, which tends to increase with the aging of the air mass over the Plains states and the Mississippi Valley, at least as long as the mass remains over a snow or ice-covered surface. Passage of the P_c air mass during its progress southward over bare ground or especially over open water, leads to a rapid heating and moistening of the lower strata. Consequently the typical N_{pc} air mass in more southerly latitudes is likely to be characterized by rapidly diminishing stability, but during the winter season it never becomes really unstable in the Mississippi Valley before it reaches the Gulf of Mexico.

We notice from Table II that the specific humidity at Ellendale is very low at all levels but with a pronounced maximum at the 2 km level, whereas the relative humidity is uniformly rather high at lower levels. The indication is that the radiational cooling of the surface air strata to very low temperatures has led to condensation and deposit of moisture from these strata. Generally speaking, values of specific humidity less than 1 g and a rapid increase of θ_E with elevation, are characteristic of the P_c air masses.

The normal flying conditions prevailing in the P_c air mass in winter in the northwestern and central United States may be readily surmised from the air mass properties. The condition will be one of extreme cold at the ground, but the temperature will be much higher at intermediate levels (1 to 2 km above ground). Bumpiness will be markedly absent, flying being unusually smooth, except perhaps for the shallow turbulence layer near the ground when the winds are fresh. Condensation forms are characteristically absent, though at the beginning of a P_c outbreak a low stratus or strato-cumulus cloud

deck may mark the top of the turbulence layer, but is likely to dissolve rapidly. Otherwise the air mass should be cloudless, high clouds indicating the presence of another air mass aloft. Occasionally the radiational cooling of the lower strata of the air mass leads to the local formation of frost smoke or ice crystal fog at very low temperatures. The intensification and lowering of the subsidence inversion and the disappearance of all surface wind in the stagnant and aging P_c air mass favors the accumulation of smoke and dust pollution in the lower levels of the atmosphere. Consequently the P_c air mass during its later history, and especially in industrial regions, is likely to be marked by unusually dense smoke haze below the inversion and by sharply marked haze layers. But the air mass in the central United States is usually too dry for the formation of any extensive dense fog below the subsidence inversion. Fog is likely to appear in the old P_c air mass first upon the approach of a warm front with a lowering warm front cloud deck and precipitation. This is a very dangerous condition for flying, as it favors not only fog formation but also heavy ice formation on the plane. However, this condition pertains essentially to the warm front zone and not to the P_c air mass as such.

In the northeastern United States, and generally along the Atlantic seaboard, the P_c air mass properties vary significantly from the characteristics which they show in the Mississippi Valley and the northwest. This is probably to be attributed to the following facts:

(1) The existence of considerable areas of open water in the Great Lakes in winter. The rapid heating and moistening which this effects in the lower strata of the cold, dry, stable P_c air masses are evidenced by the persistent low cloudiness, convectional snow flurries and relative warmth of the onshore P_c current which has crossed any of the lakes. Presumably this instability becomes rapidly less at upper levels.

(2) The presence of the highlands and numerous ridges of the Appalachians which must be crossed in the eastward advance of the P_c current. On the western slopes of the Appalachians the effect of the forced ascent of the P_c current which has already been rendered conditionally unstable over the Great Lakes is to cause general cloudiness and more or less continuous snow flurries as long as the cold air flow continues unabated. On the coastal slopes the Föhn action causes a partial or total dissipation of the cloud deck and snow flurries. However, the turbulent mixing effected by the rough terrain maintains a steep lapse rate through the lower km or more, with low relative humidity and relatively high temperature at the ground.

(3) The increasing depth and strength of the P_c outflow in the eastern United States. The rapid intensification and increasing vertical depth characteristic of cyclonic disturbances moving northeastward over the United States causes an acceleration of the P_c outflow over the eastern United States especially at higher levels. This helps to increase the turbulence in this air flow at low levels, while the rapid transport southward of air from Arctic sources at upper levels maintains a good lapse rate aloft.

These effects are to be seen clearly in the data for Boston in Table II. We note the high surface temperature in contrast to that at Ellendale, and the steep turbulence lapse rate in the first km and the moderate rate above, such that at the 3 and 4 km levels the characteristic P_c temperatures are notably colder at Boston than at Ellendale. We observe also the low surface relative humidity increasing with elevation and the almost constant value of θ_E in the first km, both of which indicate thorough turbulent mixing, while even at higher levels θ_E increases much more slowly than in the P_c air at Ellendale.

These characteristics of the P_c air mass in the northeastern United States and along the Atlantic coast explain the typical flying conditions which are met with during its prevalence in this region. As long as the cold air flow continues actively, the roughest and gustiest flying conditions which may be experienced in winter are to be expected up to considerable elevations. Along the Atlantic seaboard the skies are likely to be almost clear, with excellent visibility and, normally, only scattered fracto-cumulus or cumulus clouds, though scattered light snow flurries sometimes occur in the afternoon. In the Appalachians and on their western slopes one may expect a rather low broken cloud deck, often continuous over considerable areas, with frequent, extensive and often heavy snow squalls.

After the force of the P_c outbreak has been spent, so that the air mass becomes relatively stagnant, then subsidence, radiation and the cessation of the turbulent mixing all act to establish quickly in the P_c air mass the low inversion, thermal stability and dense stratified smoke haze so characteristic of this air mass in the middle west. Of course, this change is accompanied by the complete disappearance of the instability snow flurries, cloudiness, and gustiness.

The P_p air masses

The P_p air masses are those originating in the Arctic or sub-Arctic, which reach the Pacific coast of the United States or Canada after a more or less prolonged sojourn over the waters of the north Pacific ocean. Initially these air masses come from the Arctic source regions with properties which probably approximate those which we have found to be characteristic of P_c air, but prolonged heating and moistening over the warm waters of the north Pacific produce, to an extreme degree, the type of modification which we found to be effected in the P_c air masses in winter by the Great Lakes. They are changed from a cold, dry, extremely stable condition to one of marked conditional instability with a comparatively high moisture content in the lower strata. The data from Seattle in Table II give the average conditions in the P_p air mass as it arrives on the north Pacific coast direct from more northerly latitudes. When these air masses have made a swing southward and reach the Pacific coast from the west or west-southwest they are still warmer and moister than indicated by the data from Seattle in Table II but especially so in the upper strata. Consequently, the convective instability is less pronounced and is displaced upward to the higher strata of the air mass.

If we compare the properties of the P_p air mass at Seattle with those of the P_c at Ellendale, we note that, whereas at the ground the former is 34°C warmer than the latter and has a specific humidity nearly 15 times as great, at the 3 and 4 km levels the temperature difference is only 6 or 7°C, while the difference in the specific humidity almost vanishes. Probably 3 km is about the upper limit to which convection has penetrated in the P_p air mass. The equivalent potential temperature at this level is somewhat lower than at the ground but it begins to increase rapidly above.

As would be expected from the conditional instability and high moisture content of the lower strata of the P_p air mass on the Pacific coast, flying weather conditions are not favorable in the P_p current. Visibility is good in the absence of condensation forms but we find normally a rather low broken cloud deck, which may be solid over large areas, with extensive cumulo-nimbus formations and convective showers which are frequently rather heavy and may follow in quick succession. Winds are likely to be gusty, and flying extremely bumpy. On the western slopes of the coastal mountain ranges the clouds are likely to be low and thick and the precipitation (snow in the mountains) to be heavy and almost continuous. Such conditions will persist as long as the steady onshore flow of the P_p air continues.

It happens quite frequently in winter that a westerly flow of air from the Pacific (usually P_p air masses) continues for considerable periods of time, so that the weather conditions prevailing over the greater part of the United States may be dominated by these air masses. We have just seen the unfavorable weather conditions which prevail in the P_p air current in the Pacific coast region but this air mass is importantly modified in crossing the western mountain ranges to the interior of the country in the following ways:

(1) Much of the moisture contained in the lower strata of the P_p air mass is condensed in heavy convective showers and the heat of condensation is supplied to the air mass strata at intermediate levels.

(2) The descent of the eastern slope of the Rockies dissipates the cloud deck and convective showers in the P_p current, while the heat of condensation already supplied to the intermediate strata of the air mass and adiabatic compression (Föhn effect) cause a marked warming of the air mass at the 1 km level and above.

(3) The warming of the surface strata is checked by radiational and contact cooling over the cold continental surface and perhaps also by mixing with remnants of cold P_c air.

The effect of these various influences acting on the P_p air mass is readily seen by comparing the P_p data in Table II from Seattle with those from Ellendale, which may be taken to typify inland conditions in this air mass. At Ellendale the P_p air mass shows a very large temperature inversion and constant value of w in the first km, instead of the instability found at Seattle. The temperature increase over the Seattle values shows a maximum at the 2 km level. Probably, however, the marked increase in T and w found at 1 km and above, in passing from Seattle to Ellendale, is considerably in excess of the change which actually occurs in the air current itself, for the P_p current which reaches Ellendale comes from the west or west-southwest. It is not one of the direct northwest currents such as Seattle's data represent but one of the westerly currents which is doubtless appreciably warmer and moister at upper levels than the fresh P_p air from the northwest. However, the Ellendale data are absolutely typical for the P_p air masses which have crossed the mountains to the interior of the United States. The modification from the typical coastal P_p properties is so pronounced that the symbol N_{pp} instead of P_p is used for these air masses in the central United States.

The weather conditions which prevail in the N_{pp} air masses east of the Rockies are in general the best which are experienced in winter. Air movement is usually moderate, and convective turbulence is experienced only in the afternoon when the large diurnal temperature range found under these conditions may be sufficient to overcome the normally prevailing surface temperature inversion. Temperatures are notably mild, skies clear except possibly for some scattered high clouds and visibilities generally very good except for the possible occurrence of morning smoke haze in industrial regions.

When, however, an advancing P_p air current comes in contact with a strong outflow of cold P_c air on the eastern side of the Rockies, it is likely, as the warmer current, to ascend and advance over the P_c current along a typical warm front. Such a development may cause severe blizzard conditions in the Plains states, but this is, of course, a frontal phenomenon and in no sense a characteristic of the P_p air mass.

The T_g air masses

The T_g air masses are those which originate over the warm waters of the Gulf of Mexico and Caribbean Sea, or further southeast in the Tropics. Scarcely to be distinguished from them in characteristic properties are the T_a air masses from the Sargasso Sea region, so that this discussion really applies to both. The transitional forms of both air masses are usually referred to simply as N_{tm} (transitional Tropical maritime) without any attempt to make the very difficult distinction between N_{tg} and N_{ta}.

As would be expected from the uniform warmth of the waters in the T_g source region, marked warmth and high moisture content at lower levels is characteristic of these air masses. This is shown strikingly in Table II by the high values of T, w and θ_E at the surface and the 1 km level in the T_g air, values which are much higher than are found in any other American air mass in winter. But at Groesbeck we find at the 2 and 3 km levels a surprisingly large decrease in the moisture content of the air mass, although the value at the 3 km level, which is based on very few observations, seems rather questionable. There is no doubt, however, that this same characteristic vertical moisture distribution appears in the T_g air masses at all the aerological stations in the middle west and south, though not to quite the extreme degree as at Groesbeck. The explanation of this phenomenon remains somewhat uncertain. It may be due in part to the normally prevalent wind shift from south towards west with increasing elevation. Especially at Groesbeck, which lies near the western edge of most T_g currents, such a shift tends to bring a drier stratum of continental air above the moist surface T_g stratum. But on the other hand, this dryness is found in cases where there seems to be no shift of wind towards the west in the dry stratum. It may be that the dryness and warmth of the air at the 2 km level are due to slow subsidence in the extensive subtropical anticyclone in which the T_g air masses usually originate. If this is the case, it practically excludes the possibility of there being any extensive penetrative convection in these air masses in the source region. More aerological material is needed from the Gulf of Mexico and Caribbean

Sea to settle the question of the actual initial structure of the T_g air masses.

But whatever the explanation of the marked stratification of the T_g air masses in the southern United States, this characteristic is an important property of these air masses. We note at Groesbeck the marked thermal stability of the T_g air mass, a property which is quite generally characteristic of this mass. But in spite of this marked thermal stability of the air mass, the large decrease in θ_E, amounting to 14°C, between the 1 and 3 km levels, indicates a condition of marked *potential* instability in the air mass, which is, of course, the result of the extreme concentration of water vapor in the lowest km. Other aerological stations in the south and southwest show similar decreases of θ_E in the T_g air masses, amounting to about 10°C. The somewhat smaller value of this decrease follows from the absence of the extreme dryness in the 3 km level which is found at Groesbeck. Yet relative humidities of less than 30 percent are of normal occurrence in the upper strata of the T_g currents in the Mississippi Valley.

In spite of the marked potential instability of the T_g air masses in the south, their thermal stability is such that convective precipitation occurs rarely within the air mass in winter. But behind the warm front at which the overrunning warm current is T_g air, the precipitation is often convectively irregular and extremely heavy. With the high relative humidity observed in the lowest km of the T_g current, comparatively little forced ascent of the warm current is necessary before the potential instability present becomes available for thermal convection. In fact it occasionally happens even in winter that sufficient forced ascent of a vigorous T_g current is effected by coast line or mountains (southern Appalachians) so that convective showers are initiated, but this occurrence is restricted for the most part to the summer season when insolational heating of the T_g air mass may produce widely scattered heavy convectional thunderstorms in the eastern United States.

In the south the prevailing weather conditions in the T_g air mass are essentially those of warmth and high humidity. There is likely to be a good deal of cloudiness, especially during the night and early morning. The principal cloud forms are rather low stratus or strato-cumulus, which the sun frequently dissipates during the day. Visibility is likely to be rather poor when low clouds prevail but becomes good with the dissipation of the cloud deck. The cloud base is likely to be at only a few hundred meters elevation, while the upper boundary coincides with the temperature inversion which marks the upper limit of the extremely moist air stratum, usually between 12 and 16 hundred meters elevation. It is seldom that any precipitation is associated with this type of stratus in the south, for the inversion above is usually sufficient to prevent penetrative convection and, in its earlier history near the source region, the lower strata of this air current are not sufficiently cooled to produce the mist and drizzle which are likely to appear as it moves northward. Apart from the possible existence of a turbulent stratum near the ground in cases of strong air movement, flying conditions in the T_g air mass should be definitely smooth in the south. Frequent low stratus and rather poor visibility may prove embarrassing especially in hilly country.

As the T_g current moves northward it is continuously cooled in the lowermost strata by contact with the increasingly cold surface beneath. Over dry land this cooling takes place rather slowly but over cold water or a snow and ice surface it becomes very rapid. The natural consequence is to produce very rapidly a supersaturated stratum at the ground in the warm moist air current. If the air movement is light, this leads quickly to the formation of dense fog at the ground (the so-called Tropical air fog[3]) but since the advance of T_g air to high latitudes is normally associated with rather strong air currents, mechanical turbulence usually maintains a thoroughly mixed stratum at the ground, topped by a dense low stratus cloud deck. As the cooling continues, rather dense mist or fine drizzle is likely to fall from this stratus, so that the visibility even with rather strong wind may be reduced almost to that of a dense fog, with a ceiling of not more than one or two hundred meters. This is a condition which makes flying practically impossible, except over a perfectly

[3] See H. C. Willett, *Fog and Haze, their Causes, Distribution, and Forecasting*, Monthly Weather Review, November, 1928.

flat surface. Long before visibility becomes poor at the ground the lowering ceiling in the advancing T_g current makes flying in mountainous country impossible. For example, even in the lowest passes in the Appalachians the ceiling quickly closes in, especially on that side of the ranges against which the wind is blowing.

The data in Table II for T_g air at Boston show clearly the beginning of the cooling of the T_g air mass to the N_{tm} condition, as just described. As compared with Groesbeck we note the marked stability of the first km of the air mass at Boston, where obviously the 1 km level is just above the top of the surface turbulence stratum. But, equally striking in the comparison of the data at these two stations, is the disappearance of the dry strata aloft at Boston, the strata which were found to characterize the T_g air mass quite generally as it first advances northward from the source region. This difference is not easy to explain. Possible explanations may be looked for in the nearness of Boston to the northern portion of the T_a source region, in the depth and uniform strength at all levels of the few Tropical air currents which reach this latitude in winter or in the mixing effect of the Appalachians on all air currents reaching Boston from the southwest. However, whatever its explanation, the disappearance of the marked moisture stratification in the T_g air mass at Boston, together with the cooling of the surface strata, has as one immediate consequence the dissipation of the condition of potential instability which characterizes the T_g air mass in the south. Instead of a marked decrease we find a marked increase of θ_E in the lowest 2 km, with practical constancy above this level. This probably accounts for the rareness in the north of the extremely heavy local convective rains which may occur with the T_g warm front in the south.

The weather types which we have discussed in connection with the three principal air masses, P_c, P_p and T_g, are the predominant types which we meet with in the central and eastern United States, in winter, in the absence of marked frontal activity. We have seen how the study of the characteristic air mass properties as indicated by the aerological observations facilitates the understanding and explanation of these weather types and consequently favors especially the forecasting of those elements which are important in aviation. Probably, moreover, further aerological investigation of frontal activity and of the development of line squalls and cyclonic disturbances in the United States will show that the air mass properties are also of prime importance for the explanation and forecasting of all those phenomena which depend upon interaction at the boundary between air masses of markedly different properties.

Choice of Airfoils for Rotating-Wing Aircraft

JOHN B. WHEATLEY, *National Advisory Committee for Aeronautics*
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THE National Advisory Committee for Aeronautics has for some time been directing its efforts toward the improvement of safety in flight, and with that purpose in view has done extensive research on rotating-wing aircraft at the Langley Memorial Aeronautical Laboratory. At present an extensive program of research on rotating wings is under way in the propeller-research wind tunnel, where autogiro and gyroplane models 10 feet in diameter are to be tested to determine the influence of varying such basic properties of the rotor as the pitch angle, the airfoil section, the plan form, and the blade mass. Similar tests are being made on a model of a cyclogiro rotor 8 feet in diameter. The following analysis of the choice of airfoils for these rotors is supported by work that has already been completed; much valuable information concerning this and related subjects is anticipated from the current program.

Rotating-wing aircraft may be divided into two main classes: those normally employing power-driven rotors for sustentation, such as the helicopter, helicogyre, and cyclogiro; and those employing autorotating wings for sustentation, such as the autogiro and gyroplane. The autogiro and helicopter are familiar types. The helicogyre is an aircraft supported by a power-driven lifting propeller which is rotated by means of an additional propeller on each blade of the main screw. The cyclogiro is supported by a paddle-wheel rotor on each side of the fuselage, rotating about the lateral axis. The gyroplane is quite similar aerodynamically to the autogiro except that the blades on the gyroplane rotor are free to rotate only about the span axis, and the opposite blades are rigidly joined; lift on opposing sides of the rotor is equalized by rotation of a blade pair about its span axis.

The aerodynamic characteristics of an airfoil section required for the optimum performance of a rotating wing are the same regardless of the type under consideration. It is true, however, that the choice of the proper airfoil is more critical for the autorotating systems than for the power-driven; for this reason, the following discussion will be concerned with the autogiro and gyroplane rotors. The aerodynamic similarity between these two types is so complete that the analysis applies with equal validity to both systems.

The autogiro is a windmill of low pitch operating at large angles of yaw and maintaining a condition of zero aerodynamic torque during a state of steady autorotation. This condition means essentially that the average moment, during one revolution, of the blade element chord forces about the axis of rotation is zero, the chord force on any element being the sum of two components of opposite sign, and being derived from the lift and drag of the element. The torque variation with rotor speed is such that a decrease in speed in any state of operation generates an accelerating torque, and conversely; the rotation is therefore stable.

The optimum airfoil for a rotor of given geometrical form is defined as the airfoil that gives the largest maximum lift-drag ratio of the rotor. It has been shown by Lock (British R. & M. 1127) that by consideration of the energy losses in the rotor, the ratio of drag to lift can be expressed as

$$D/L=\sigma\delta(1+3\mu^2)/8\mu C_T+\tfrac{1}{2}C_T/\mu(\mu^2+\lambda^2)^{\frac{1}{2}}, \quad (1)$$

where D/L is the drag-lift ratio
σ is the ratio of total blade area to swept disk area
δ is the average profile-drag coefficient of all the blade elements
μ is the ratio of the component of forward speed in the plane of the disk to the tip speed of the rotor

λ is the ratio of the axial velocity at the rotor to the tip speed of the rotor
C_T is the rotor thrust coefficient and

$$C_T = T/\rho\Omega^2 R^2 \pi R^2, \tag{2}$$

where T is the rotor thrust
Ω is the rotor angular velocity
R is the rotor radius
ρ is the air density.

Assuming that the lift of the rotor is equal to the lift component of the thrust, a simplification proved valid by experimental results,

$$L_r = T \cos \alpha, \tag{3}$$

where L_r is the rotor lift
α is the angle of attack of the rotor disk.

The minimum drag-lift ratio occurs at low angles of attack where the $\cos \alpha$ is almost equal to unity and the factor λ has been found negligible with respect to μ. The equation for the drag lift ratio then becomes

$$D/L = \sigma\delta(1+3\mu^2)/4\mu^3 C_{L_r} + C_{L_r}/4 \tag{4}$$

and the best airfoil is one that results in a minimum value of (4) when the expression is a minimum insofar as variations of the tip-speed ratio are considered. A typical curve of D/L as a function of the tip-speed ratio μ is plotted in Fig. 1, where the minimum value occurring near $\mu = 0.4$ is shown. This value of μ will differ slightly with varying solidities and pitch angles, but is approximately the μ for minimum D/L of any rotor.

Although the airfoil-section characteristics influence C_{L_r} indirectly in Eq. (4), the average profile-drag coefficient of the blade δ is the only parameter determined directly by the section. The remaining parameters in (4) are almost wholly independent of δ, so D/L must decrease as δ decreases. The analysis of experimental results has shown that δ may be calculated as the average drag coefficient of the airfoil section between zero and two-thirds maximum lift, the range averaged increasing slightly with μ and with the pitch angle.

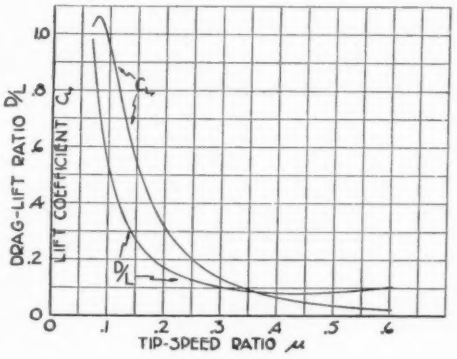

FIG. 1.

Another method of improving the D/L ratio consists of increasing the rotor pitch angle, which will increase the rotor lift coefficient at a given tip-speed ratio. While it is not apparent from Eq. (4), when D/L is a minimum the first term in Eq. (4) is always large in comparison with the second, so that an increase in the lift coefficient decreases the sum of the two terms. The autorotation of the rotor is stable, however, only at pitch angles less than a maximum value determined by the characteristics of the airfoil section, more particularly by the chord-force characteristics of the airfoil. At pitch angles which exceed this maximum value, the autorotation of the rotor breaks down for the following reasons.

Because of the phenomenon known as tip losses, the tip of a rotor blade has an effective angle of attack of zero regardless of pitch angle or operating conditions, the effective angles of attack of the remaining portions of the blade increasing as the center of the rotor is approached. Considering a forward chord force as positive, at low angles of attack the chord force of an airfoil is negative, increasing with angle of attack to a positive maximum near the stalling angle of attack, and attaining large negative values at higher incidences. It is apparent, then, that the outer portion of the blade develops an aerodynamic moment resisting rotation, which must be neutralized by moments developed at smaller radii aiding rotation. It must be remembered also that where the velocities of rotation and translation are additive, the automatic change in angle of attack along the blade which equalizes the rotor lift about the axis of rotation will result in low angles of attack over the major portion of the blade; where the velocities are subtractive, the angles of attack reach large values quite close to the tip and

even stall the elements. From these considerations, the torque aiding rotation will be developed by a part of the blade when the position of the blade is such that the velocity of any element with respect to the air approaches the average value of its velocity during one revolution, or the position will be approximately upstream or downstream. Even in these positions, however, the variation of angle of attack with radius is such that a part of the blade is stalled near the center of the rotor. As the pitch angle is increased, the stall of the blade elements extends out along the blade, decreasing the portion of the blade developing positive torque and increasing the negative torque. It is now obvious that the greater the magnitude and angular range of the positive chord force, the more advantageous are the autorotative properties of the airfoil section, and the greater the pitch angle which may be used on the autorotating rotor. Quantitative analysis of this property is, however, impossible and even comparative analysis is difficult because of the uncertain influence of Reynolds number on the airfoil characteristics. Much of the rotor operates at low scale because of the vector addition of rotational and translational velocities, and in those regions the airfoil characteristics are problematical, since no data on airfoils are available showing the change in general characteristics as a function of scale. A further unknown element, insofar as the blade elements are concerned, is the turbulence of the flow in which they operate, which has an important influence on the aerodynamic characteristics of the airfoil section. Certain general rules may be applied with discretion to predict low-scale characteristics from full-scale results. Thus the change to a lower scale is liable to cause a smaller increase in drag with cambered sections than with symmetrical ones; similarly, the increase in drag sustained by thick sections is generally less than that sustained by thin ones. It must be admitted, however, that no exact method can as yet be presented for the determination of the best possible autorotative airfoil, beyond the vague generalities just stated. The existence of large positive chord forces at full-scale Reynolds number may be considered a good indication, but no more.

The method of choosing an airfoil from aerodynamic considerations for the autogiro or gyroplane rotor is based on the criterion that the airfoils have low drag coefficients from zero to three-fourths maximum lift. Some weight may be given to an analysis of the chord force provided that the low-scale characteristics may be estimated, but present knowledge is too limited to define the relative importance of this criterion in comparison with the previous one. When choosing an airfoil for an actual rotor, aerodynamic reasons alone will not dictate the choice, since structural considerations are of equal importance. Fortunately, it is true that structural considerations practically disappear beyond 50 percent of the radius whereas aerodynamic considerations become of major importance in that range.

The optimum autogiro or gyroplane rotor blade, as indicated by the previous analysis, would consist of a 12 or 15 percent thick symmetrical airfoil for the inner half or two-thirds of the radius; the airfoil would taper in thickness and become a flat plate near the tip. It is estimated that a blade of this type would increase the maximum lift-drag ratio of a rotor by about 25 percent over the value resulting from blades having a constant airfoil thickness of 12 percent. The improvement in performance to be expected from this increase in lift-drag ratio depends upon the cleanness of the aircraft; for a well-streamlined type the top speed would increase by about 5 percent.

Second Annual Meeting
Of The
Institute of the Aeronautical Sciences

The Second Annual Meeting of the Institute of the Aeronautical Sciences was held in the Physics Building of Columbia University, New York City, on January 31, 1934. The facilities of the Physics Building, as well as the Faculty Club, were provided through the courtesy of Professor George B. Pegram. The Technical Sessions commenced at 10 A.M. and continued until 1 P.M., when the members lunched together at the Faculty Club. The Technical Sessions were then continued in the afternoon until 5 o'clock, when the Annual Meeting of the Institute was held.

At seven o'clock the Annual Dinner of the Institute was held at the Faculty Club. About two hundred members and guests attended the meetings.

The following summaries cover fully the discussion on all the technical subjects except that of "Power Plants."

Several members have requested the editor to print in full the remarks of Professor C. F. Taylor of the Massachusetts Institute of Technology, on the nature of detonation on account of the importance and interest of the ideas there developed. Space is, unfortunately, not available and readers are asked to await the next issue for this. It should be noted here that C. F. Taylor has recognized in the physical-chemistry of combustion the phenomenon of time-lag. By close reasoning from this property, he clarifies much that has seemed contradictory and obscure. Written comment from those who attended the meeting is invited.

Technical Sessions

In opening the meeting Dr. J. C. Hunsaker, President of the Institute, explained his idea of the Institute of the Aeronautical Sciences as a meeting ground for workers in the several fields of science applied to aeronautics, where they may become acquainted with one another's problems. It is becoming increasingly important in all scientific work to appreciate not only the advances in allied fields but also to appreciate the reasons for such investigations and the trend of the resultant information and conclusions. Progress, like the advance of an Army, is not continuous nor on the entire front at the same time. Rather is progress to be noted by an advance first here and then there. The results of an advance at one point may often be quickly applied elsewhere to advantage.

With this conception of the aeronautical sciences, Dr. Hunsaker had arranged that the annual meeting should depart radically in form from the usual meeting of a professional society and explained that there would be no reading of papers nor description of work accomplished but that this meeting should literally be a meeting of people engaged on many fronts who mutually shall inform themselves of the general situation. For this purpose, there would be held a series of discussions of current progress led by members who are recognized by all of us as leaders in their respective fields of aeronautical science.

It seemed fitting and appropriate to begin with a discussion of the position of meteorology as applied to aeronautics; first, because the atmosphere is the ocean whose conquest is the final objective of all aeronautical endeavor, and second, because the Institute is honored and gratified to have supplied from its membership the newly appointed Chief of the Weather Bureau of the United States, W. R. Gregg.

As President for the first year of the Institute's existence, Dr. Hunsaker took reflected glory from this appointment and congratulated the Institute and the Aeronautical industry on their good fortune. Mr. Gregg was then requested to take charge of the meeting for the consideration of meteorology as it now stood and as it was expected to develop.

Meteorology

The meteorological part of the day's program was opened by W. R. Gregg, newly appointed Chief of the United States Weather Bureau. Mr. Gregg gave a brief account of the present status of weather service for aeronautics and indicated some of the lines along which it is hoped that further development may take place.

W. R. GREGG

Present status: The speaker stated that, notwithstanding drastic reductions that have been necessary in connection with the Government's economy program, weather service is still furnished for the entire Federal airway system, comprising at the present time approximately 26,000 miles. About half of this mileage, namely, 13,000 miles, is provided with continuous, 24-hour service, including hourly reports from an extensive network of stations and short period forecasts, especially designed to meet the needs of the pilots.

The remaining 13,000 miles of airways have at present much less flying, in some cases only one or two daily flights each way, and for these the service is not on a 24-hour basis but is so organized as to provide reports and forecasts only for the scheduled flights.

The forecasts are issued from 10 of the largest terminal airports and cover a period of 4 to 6 hours. At these airports and also at about 55 others trained personnel are on duty day and night, thus providing direct contact with pilots and with other officials of air transport companies. To these stations are forwarded reports from some 600 intermediate stations, the observations at these points being made by non-professional but well trained personnel.

In addition to the foregoing, upper wind observations by means of pilot balloons are made at about 70 stations well distributed over the country and the data are transmitted to all airports in the airway network. Finally, observations of upper air temperatures and humidity conditions are made with airplanes at 4 stations of the Weather Bureau and 6 of the Bureau of Aeronautics, Navy Department, and these likewise are widely distributed. Transmission of data is accomplished in part by the Department of Commerce communication system, teletype and radio, and in part by commercial telegraph and telephone.

Future program: Mr. Gregg called attention to a report recently submitted by a subcommittee of the Science Advisory Board, appointed by President Roosevelt to study the scientific work of the Government. This report contains several constructive recommendations, among the most important being an increase in the number of weather maps from two to four each day, and expansion of the upper air observational program by means of airplanes.

The additional and more detailed data thus furnished will make possible a greater use than is now made of the so-called Air Mass Analysis system of forecasting. Air Mass Analysis consists, in brief, of a detailed study of masses of air of decidedly different structure as to temperature, moisture and wind that meet along an irregular line variously called "discontinuity line," "polar front," "wind shift," etc. These masses of air, cold and dry from polar regions, warm and humid from equatorial, do not readily mix but tend to preserve their individual identity, the warm, moist air being forced to rise above and flow over the denser cold air, with resulting condensation and precipitation and other attendant phenomena which give us most of our stormy and turbulent weather.

The Weather Bureau accepts these and other recommendations of the Science Advisory Board as a basis for further future development. While no definite statement can yet be made as to when or to what extent this development can be realized, there is reason to believe that a beginning at least can be made soon, in part through some reorganization of present service and in part through cooperation with other Departments, including War, Navy and Commerce, particularly in the upper air part of the program.

Mr. Gregg concluded his remarks by describing briefly some lines of work now in progress, the results of which will make possible the publication at an early date of pilot charts of the upper air, similar to the well-known mariners' pilot charts, and statistical tables and charts showing the frequencies of fog, low ceiling and visibility, thunderstorms, winds of various directions and speeds, and other conditions of special interest to aeronautics. Seasonal and diurnal variations will be shown for a large number of airports, intermediate landing fields and other points in all parts of the country. They will be extremely useful in connection with the laying out of airways, the orientation of runways and the determination of flying schedules for aircraft of different cruising speeds. They will provide the first fairly comprehensive climatological summary especially designed to meet the needs of aviation.

DR. J. H. KIMBALL

Dr. James H. Kimball of the U. S. Weather Bureau said that of all the methods tried in exploring the atmosphere the use of the airplane had been most successful, this being especially true in efforts to secure a cross section of the heat and moisture content of the air mass. The proposal to further this work means the employment of pilots to take meteorographs aloft. He pointed out that while the records obtained will be largely automatic registrations, the value of the flights will be enhanced by good supplemental eye observations if the pilots in their descriptions will adhere to the use of terms within their dictionary significance.

Particularly, he asked that they discontinue the use of the word fog when cloud is meant, since this inaccuracy caused confusion and sometimes hampers the solution of a problem by injecting the question of credibility into the pilot's report. No uncertainty as to what is observed is possible if the pilot employs the use of the words fog and cloud in their established meanings. When a cloud rests on the earth's surface it is fog, but not otherwise. All pilots are familiar with the International Cloud classification and usually they are able to correctly name the cloud they are flying in.

Attention was called to the distinguishing feature— size of droplets— between fog and rain, quoting recent measurements of fog particles made at M. I. T. which showed them to have a diameter of the order of one twenty-five-thousandths of an inch, while the smallest rain drops, mist, may be measured in hundredths of an inch. If water collects on the windshield it is from rain, notwithstanding the drops may be too small to be distinguished by the unaided eye. The speaker said that failure to differentiate between fog and rain had seriously impeded the study of ice formation since laboratory meteorologists, knowing that all the moisture in a large cloud if condensed would produce but a few pounds of water, were unable to recognize it as a hazard. But rain that is undercooled, even if falling in the form of very small drops, is quite another matter. Fog that is congealed may sometimes be observed adhering to sheltered places in the form of fine ice crystals— properly called rime, while the layer of ice formed from cold rain is known in meteorology as glaze. Sleet is something else. It is simply rain drops that have become frozen in passing through a layer of cold air. Sleet reaches the ground in the form of ice particles.

If visibility along the surface of the ground is impaired by moist particles the speaker urged that the impairment be called fog, leaving the term haze to describe obscuration due smoke, dust and other dry precipitates. Haze is characteristic of protracted hot dry periods. Then the surface dust is lifted by convection and, being very light,

remains suspended for long periods and gives to the sky and horizon a milky appearance.

Observations of wind, temperature and humidity throughout all levels of the air mass from the earth's surface to at least the height of cirrus clouds have long been recognized as essential to the study of the air, and their need has been felt particularly since meteorologists became conscious of the interrelations of these elements in streams or islands of air that tend to remain intact for days at a time. More than thirty years ago Professor Frank H. Bigelow of the Weather Bureau proceeded from this conception to the development of his counter current theory of the formation of cyclones and anticyclones. Most of us have recognized the sharp line of demarcation separating the muggy air preceding some thunderstorms from the cool dry air that follow them; and equally obvious near the center of an area of low barometer is the horizontal layer of discontinuity shown by clouds from the southwest that appear through breaks in the lower murk coming from some easterly direction. But the contiguity of similar air particles is best seen in the cold waves that invade middle latitudes from the Arctic.

The speaker displayed three isobaric charts that had important bearing on recent Atlantic weather. The first showed an area of high pressure (30.50 inches) lying south of Newfoundland on January 23d, 1934. It came from Northwest of Hudson Bay where it was charted on the 19th. Crossing the coast on the night of the 21–22d and thereafter moving swiftly eastward. Coincidently, the eastern half of the ocean was occupied by a warm high (major axis, Northeast-southwest) that was drifting slowly eastward. On the 23d, when the intervening space had closed to a steep trough, the interaction of the cold dry air from Canada and the moist warm back-flow from the eastern high, produced a severe storm. The Steamship Europa, then in the neighborhood reported winds of hurricane force. Pressure distribution of this type is of common occurrence in the North Atlantic. It is always a menace to aircraft, since a considerable number of advantageously placed observations, many more than are usually available, is necessary to foresee with definiteness the localities of storm development.

The second chart illustrated an air mass developing southward from the Greenland-Iceland region during the closing days of October, 1933. It is of particular interest since the easterly winds of its advancing front seriously impeded the return flight of the Graf Zeppelin. The principal high was reenforced by another moving east from Newfoundland. The head winds so seriously handicapped the dirigible that the course near midocean, which had previously lain along the 40th parallel, was changed to northeast, cutting directly across the belt of strong winds. The new course was maintained until the center of the high was reached near the 50th parallel. There the winds were light, and after a short flight eastward the craft came to tail winds that lead directly to southern Spain.

The third chart, that of July 12th 1933, was shown to illustrate the pressure distribution prevailing at the time of the Balbo flight from Iceland to Labrador. Since the weather feature most essential to the success of this flight was clear air at landing, the start was deferred until an anticyclone was found to be approaching the Labrador coast from the interior of Canada.

W. F. McDONALD

W. F. McDonald of the Marine Division of the United States Weather Bureau stated that the Civil Works program for handling Marine records accumulated in the files of the Weather Bureau had been a valuable opportunity to secure much needed data. For many years ships have sent in weather reports in the form of a "trip records." The succession of observations, therefore, followed the course of the observing vessel, and the reports passed into a general file according to the ocean concerned. Although the ships' observations were fairly comprehensive, usually including valuable notations regarding the general state of the weather, as "overcast," "rain," "passing showers," "high visibility," etc., in Beaufort's short notations, these data have in the main been passed over in the older program of extraction of material. With the new value placed on such details (thanks to the Norwegian system of weather analysis) and with the growing demands of transoceanic aviation upon us, there was now pressing need to get into these hitherto unused details of these ships' weather observations.

Studies for selection of oceanic flying routes raise such questions regarding thunderstorm areas or bands; the real hazard of sleet; low cloud, or squall condition over the different portions of proposed routes; and the prevalence of more consistently favorable flying weather.

To answer such questions demands that the massed records be reclassified and reorganized into files which will draw into clean-cut groups of observational material, all the available reports related to individual oceanic locations, or suitable ocean squares of latitude and longitude. The small regular staff of the Marine Division was not itself able to analyze the masses of records available, but today almost one hundred Civil Works Administration employees are engaged in New York in the project of reducing some two million ships' observations (covering the last twenty years) to the form of punch-card records for machine sorting and tabulation. The punching is planned to enable us to break down the files to unit areas as small as ocean squares only one degree of latitude and longitude on each side. A total of one hundred and forty other workers are engaged elsewhere, in converting earlier and more heterogeneous ocean weather observations to a form which can be manually sorted and filed.

If the objectives, towards which these 241 people are being led in the marine phases of the Weather Bureau's C.W.A. project, are even reasonably approximated, the Marine Division will, in the use of the accumulated records, be placed many years ahead of the position attainable under its fixed, regular basis of operation. It will be able at last to approach the task of sorting out some of the elements of a "dynamic climatology" of the North Atlantic Ocean, and to a poorer degree, of the North Pacific and other oceans.

Simple averages of weather elements will for many areas be amplified into month to month histories. The sequence

of weather changes over the oceans can be partially investigated and recorded. It will be possible to begin some of those studies, so long needed, regarding the relations of oceanic and continental weather conditions; possible sources of climatic fluctuations; weather abnormalities; etc.; and to check to some degree upon the results of such short-period weather surveys as those recently undertaken along the Greenland-Iceland route to Europe. A limited weather survey may or may not be representative of the long-term complexion of the weather conditions over such a route.

PROFESSOR J. BJERKNES

In reply to a question as to the importance of sounding balloon ascents into the stratosphere in the application of the air mass analysis methods to American weather forecasting, Dr. J. Bjerknes, Professor of the Geophysical Institute, Oslo, Norway, replied that such soundings do not constitute at all a part of the daily practice of forecasting by these methods. He added, however, that much further investigation of the mutual interaction of the stratosphere and troposphere in the genesis and development of our weather phenomena will be necessary before we can hope to really understand these processes and to forecast the weather with complete accuracy. Consequently as a research problem such investigation of the stratosphere by sounding balloons holds a key position in the future development of weather forecasting. Therefore, if it is desired in this country to take and hold a leading position in the development of modern synoptic and theoretical meteorology, it is important that investigations of this type be actively pursued by some agency in the United States. But Professor Bjerknes emphasized the fact that this is in the nature of a research project only, and that the introduction of the air mass analysis methods to American weather forecasting should not be considered as in any way dependent upon the establishment of such sounding balloon work.

H. C. WILLETT

H. C. Willett, of the Meteorological Division, Massachusetts Institute of Technology also referred to the Norwegian "Polar Front theory of weather forecasting." Mr. Willett pointed out that this method of explaining and forecasting meteorological phenomena depends upon the concepts of the *air mass* and *front*. An *air mass* is an extensive portion of the earth's atmosphere which approximates horizontal homogeneity in its properties, i.e., uniformity in the vertical distribution of moisture and temperature. It is found that there are definite air mass types which appear in any locality with certain characteristic properties that depend upon the source region from which the air mass comes and the path which it has followed. The *front* is the transition zone of rapid horizontal change of meteorological elements which must mark the boundary between two adjacent air masses of different properties.

The weather at any point depends upon the sequence of air mass and front passages at that point. Upon the properties of the air mass must depend the weather within the area covered by that air mass, including such elements as, temperature and vertical lapse rate, wind structure (smooth or turbulent), horizontal visibility, and if present the cloud types (convective or stratiform), and precipitation type (shower or drizzle). Upon the interaction between the two air masses at the front depend such phenomena as the formation of broad cloud and precipitation zones of the cyclonic type, the actual genesis and development of cyclonic disturbances (centers of low pressure) and the formation of line squall phenomena. Consequently weather forecasting by the air mass analysis method requires in the first place a correctly analyzed weather map, or one on which all the air masses and fronts are correctly located and designated. The problem of forecasting then reduces to the correct estimation of the future displacement and modification of the front and air mass entities, with particular attention to the potential development of frontal disturbances.

In discussing the improvement in weather forecasting which may be hoped for through the use of the air mass analysis methods, Mr. Willett expressed himself as optimistic about the possibilities. He pointed out that the great advantage of this method is that the analysis of the weather map gives the forecaster a rather complete and precise representation of the existing state of the atmosphere, or a definite physical picture by means of which he can coordinate and interpret all the observational material he can obtain. This makes possible the intelligent utilization of an unlimited amount of observations from the upper atmosphere, which should lead to a decided improvement in our understanding of weather changes and weather forecasting as our network of aerological stations is increased. This forecast method is especially useful in accurate local short-range forecasting, such as that required of airport meteorologists, because of the precision with which the location and movement of frontal phenomena can be handled over short periods of time, and because of the close correlation between the air mass type and the characteristic meteorological phenomena of all sorts which accompany each type. Even in the field of long range weather forecasting it seems possible that the study of the aperiodic displacement of the principal anticyclonic centers of action, together with the zones of maximum frontal activity between them, may offer one of the most promising methods of attack on this problem with which so little progress has been made.

In reply to a question as to what observational data in addition to that now provided for the forecaster by the United States Weather Bureau would be desirable from the point of view of the forecaster working with air mass analysis methods, Mr. Willett made the following three suggestions:

1. In the regular surface station reports the provisions of the International Code should be adopted in reporting the state of the weather and the cloud forms, which are two elements of great importance in air mass analysis and especially well provided for by that code.

2. That in the choice of the new Weather Bureau network of aerological stations (airplane) special effort should be made to locate stations at especially strategic points which have hitherto been neglected. Such points are the Gulf of Mexico and Caribbean Sea section, the north

Pacific coast of the United States, and the north central portion of the Great Lakes region.

3. That the establishment of a few mountain summit stations, such as that now temporarily maintained on Mt. Washington, would be a highly desirable feature in the Weather Bureau network of stations. A few such stations would make possible, by means of continuous, automatic records, a more complete analytical study of air mass and front passages and their structure at upper levels than can be gained by intermittent airplane soundings alone.

LIEUTENANT T. J. O'BRIEN

In discussing the improvements in the Weather Service in the United States Lieutenant T. J. O'Brien of the Bureau of Aeronautics, Navy Department said that the Aerologists of the Navy were enthusiastic followers of the Norwegian methods of air mass analysis as developed by Dr. Bjerknes and his colleagues. By means of post graduate courses at the Massachusetts Institute of Technology the Navy has trained 24 officers in these methods of air mass analysis and two of these officers have received advanced training under Dr. Bjerknes at the Geophysical Institute, Bergen, Norway.

As a result of his experience in forecasting weather over the oceans for flight operations of several hundred airplanes from the Aircraft Carriers *Saratoga* and *Lexington* Lieutenant O'Brien said that he had been impressed by the need for more weather reports from ships at sea and for more complete information in the reports. He felt that there should be some means of training the observers on merchant ships in the methods of making accurate and complete observations of the weather conditions at sea.

Lieutenant O'Brien further stated that the Navy would be glad to cooperate to the fullest extent in carrying out the meteorological recommendations of the Science Committee. In the matter of airplane observations the Navy soon expects to make daily flights from the Naval Air Stations at Lakehurst, N. J., Philadelphia, Pa., Annapolis, Md., Quantico, Va., Canal Zone, and Hawaii in addition to those now being made from the stations at Washington, D. C., Norfolk, Va., Pensacola, Fla., San Diego, Cal., Sunnyvale, Cal., and Seattle, Wash. He felt that the teletype system of the Department of Commerce was a very valuable addition to the weather reporting system of the Weather Bureau. By eliminating from the airways teletype circuits all traffic which does not concern weather reports or forecasts and giving more information in present reports the teletype system would be an even more valuable supplement to the regular Weather Bureau system. It was possible to transmit over teletype circuits at intervals of four or six hours a very complete weather map of the entire country. To be of most value the three sections of the country-wide map should be transmitted as one continuous operation instead of sending one section an hour later than the next, as is done at present. By means of these frequent maps the use of air mass analysis methods would be greatly facilitated since it would be possible to follow the air masses from map to map and to determine accurately the rate of movement of fronts.

RADIO

Examination of the status of Aviation Radio was begun by Captan A. Raymond Brooks of the Bell Telephone Laboratories' Air Group. After referring to the parallel time-development of the aeronautical and radio arts from theory to practical application, the summary offered by the speaker was to the general effect that the quality and reliability of the radio itself is equal to that of today's airplane.

CAPTAIN A. RAYMOND BROOKS

"The importance of radio in operation and control has come to be so fully appreciated throughout the industry that airplanes and engine designers now exhibit laudable cooperation in such matters as bonding, shielding, and proper regard for apparatus installation, manipulation and maintenance problems. And on their part the radio researchers have gradually approached the desired space and weight economy in the production of airplane two-way and beacon sets with multi-frequencies, long range and simplified and automatic controls. . . .

"Apart from the pressing problem of overcoming present restricted frequency allocations through use of the promising ultra-high frequency band the most fruitful approach to betterment appears to be in further work on blind landing aids and more intensive application to solve the question of future power plant and antenna requirements. . . .

"As to power plant—the gamut has ranged from the wind-driven appendage to the huge overweighted engine driven generator dynamotor combinations. Consideration of possibilities or requirements indicates use of flexible shaft driven power units on the one hand and of separate small gasoline electric units on the other—the latter having some definite advantages including the use of alternating current for general utility. . . .

"The antenna problem demands hand in glove probing by radio and aeronautical engineers. Starting in with the trailing wire with 'fish' the cycle has turned completely through various types of pole and wire systems with, in the main, unsatisfactory results as to efficiency of output, icing, and downright instability, causing a late return to the trailing wire, this time, however, issuing from the fuselage tail. The designers might well consider the idea of electrically driving insulated wings or sections of wing or body, or at least of determining the best mounting for masts,—for example, in one case the rod is a detriment and in another greater speed is claimed because of location. The true answer is seemingly not yet clear. . . ."

Following his opening remarks Captan Brooks introduced Mr. F. M. Ryan who is in charge of aviation and other mobile radio apparatus development at the Bell Telephone Laboratories.

F. M. RYAN

F. M. Ryan of the Bell Telephone Laboratories described the two-way airplane-to-ground radio telephone system now in most general use on the domestic airways.

Present Two-Way Radio Telephone System

"The present system operates in the medium high frequency range. It is the general practice to use a fre-

quency of about 5 or 6 megacycles for daytime transmission and one of about 3 megacycles for night transmission. The ground stations are located at intervals of 200 miles or less along the airways and are of 400 watts power. Telephony is employed exclusively.

"The airplane equipments are of 50 watt capacity and are arranged for complete remote control from the cockpit including instantaneous shift from day to night frequency. By the use of piezoelectric crystal frequency control, all necessity for adjustment of tuning controls by the pilot has been eliminated. Fixed antennas are in general use. However, these antennas have been found in many cases to have undesirable aerodynamic properties on new high speed transport ships, and attention is therefore now being directed toward the development of satisfactory trailing wire antenna systems.

"Both transmitter and receiver ordinarily obtain their primary power supply from the main airplane 12-volt storage battery which, in turn, is charged from a voltage regulator generator geared to one of the airplane engines. A modified power supply arrangement has been evolved employing a double-voltage engine-driven generator which also may be operated as a dynamotor.

"The subject of power supply for the radio equipment and other accessories on the airplane is one which I believe should have the careful consideration of those of your membership charged with the responsibility of air transport design. The present 12-volt system is, in many cases, badly overloaded and in any event fails to offer the necessary capacity for new important accessories. It seems certain that there would be an advantage in adopting a higher voltage system, thereby reducing the load currents and consequently the size and weight of conductors. The question must be settled as to whether this higher voltage system should be direct current or alternating current and, if alternating, of what frequency. Frequencies from that of the usual commercial supply, 60 cycles, up to 800 cycles or more, have been considered. The power supply plant probably should be driven by an auxiliary engine rather than one of the propulsion motors. Early standardization of a new electrical power plant suitable for transport use would greatly accelerate the design of improved radio equipment and, no doubt, other accessories.

Future Communication Requirements

"The present ground-to-plane radio telephone system briefly described meets reasonably well the present-day requirements of air transport. I think it is appropriate, however, for us to consider what the requirements of this service will be when say five or six thousand airplanes are being employed in it as compared with the five or six hundred that are in use today. Certainly many more simultaneous telephone conversations will be required than at present. Some of the additional frequency channels required for communications can, no doubt, be provided in the medium high frequency range which is used at present. Apparatus is already under development to bring this about. However, there is a definite limit of the number of channels that can be so provided. Additional channels must be sought in other portions of the frequency spectrum. The organization with which I am associated and others have therefore explored the so-called ultra-high frequency band (frequencies 30 to 60 megacycles, wave-length 10 to 5 meters) in an effort to determine whether it is suitable for air transport service. As might be expected, these waves have been found to have many attractive properties but also definite limitations. One of these limitations is that almost regardless of the power employed communication can only be carried on for a short distance beyond the horizon. For ordinary altitudes of flying, this means roughly that a range of 15 miles is about all that can be counted on with certainty. Splendid communication is obtained, however, up to this distance, the transmission being much less subject to fading than that at the medium high frequencies.

"In spite of the rather limited range of the ultra-high frequencies, a very satisfactory transport plane-to-ground radio telephone system can be set up employing them. It would of course be necessary to locate the ground stations at more frequent intervals say every 20 or 30 miles along airways, and to provide means of extending the telephone circuit from the plane to one of these ground stations through to the terminal of the route. This can best be accomplished by the use of a wire telephone circuit paralleling the airway with these ultra-high frequency ground stations arranged for connection to it. Such a system will involve a somewhat greater outlay for the ground plant than the one now in use. It will, however, have the decided advantage of permitting the use of airplane equipment of very limited power output and consequently reduced size, weight and cost. As the number of planes flown over the airways increases, it can be expected that there will be a saving from this sort of an arrangement as compared with the present system."

HARADEN PRATT

In discussing radio communication problems for Aeronautics, Mr. Haraden Pratt, Vice-President and Chief Engineer of the Mackay Radio and Telegraph Company, said that European commercial aviation became established somewhat in advance of general commercial activity in this country. In adapting radio communication to its needs, it naturally used the equipment and methods which were available at that time, over a decade ago. Radio, as then employed, had been built up around the longer wave-lengths, largely those above 500 meters, and use was not made of the shorter wave-lengths, the advantages of which were not fully realized and had, therefore, not been put to practical use. Accordingly, in Europe an aircraft to ground radio system became established using these medium long wave-lengths, with still longer wave-lengths generally employed for service between airports and for handling meteorological and allied information.

One of the characteristics of these longer wave-lengths is that of limited range. Another is the prevalence of atmospheric noise. Therefore, a growing demand for better radio communication developed as the distance of flights increased, and in order to secure communication, recourse was had to the use of shorter waves, as for example, in the French military air services when regular flights were

established between France and her tropical colonies. The atmospheric radio noises encountered on the longer waves made their use in the tropics almost impossible. With the short waves, long range with freedom from noise interference was possible, therefore, these far flung services were able to expand and enjoy the benefits of radio communication.

Unfortunately, because of its early start, aviation in Europe became provided generally with an extensive radio communication network built up on the longer waves, and it is noted that today this now somewhat archaic system still predominates over there. Large investments in equipment and the strong establishment of the habit of employing this system, have operated against the adoption of now proved better methods. In the United States, the later development of commercial aviation fortunately permitted communications with the more flexible short wave method, to get started early without the heritage of an older system to stand in its way.

Since the shorter waves were not practically available and all types of radio communication were carried on with the longer waves, much congestion prevailed, which was accentuated by the growth of radio broadcasting. Wave assignments were scarce and the air services were forced to get along with very few of them. Thus in Europe, even today, a rather restricted use of radio exists, and as the number of aircraft in flight has increased, it has become necessary to curtail communications so that essential contacts can take place. Airplanes must often await their turn to transmit or receive important messages. Besides the restrictions mentioned, the longer waves involve rather large and heavy equipment, which, of course, has been a handicap.

An examination of the European situation now, however, reveals a very definite trend toward still shorter wave-lengths than are in use here. The ultra-high frequency field of wave-lengths is being exploited both experimentally, and more than experimentally. While these very short waves do not have the long distance range properties of the more usual short waves, they lack the somewhat erratic behavior of these waves when used over short distances. They solve the problem of congestion. Frequencies available are numerous and can be repeated in different parts of the country. Furthermore, the distances on the busier airways are not large. Also, the equipment required becomes much smaller and lighter and full use of radio, both for communication and navigational purposes, becomes a practical possibility. It is not essential to the practical operation of such a system, that aircraft in flight must await their turn to get in on the line. It is hoped that serious effort will soon be noted in the United States, in this ultra-high frequency field, for practical use.

Just a few days ago, a commercial system was placed in operation across the English channel, by the French and British Air Ministries, for the dispatching of airplanes, which employs the very short wave-length of about 17 centimeters. Such short waves exhibit many of the properties of light, and optical methods of studying and handling their transmissions can be employed. This cross channel system permits the use of telegraph printers, or of telephony, and furthermore, can be connected through automatically at the terminals, to wire line-extensions, if desired. This interesting commercial development shows the present downward trend in the length of radio waves used abroad, for aeronautic and allied radio communication services.

Metallurgy

A. V. De Forest

The discussion on metallurgy was opened by A. V. De Forest, of The A. V. De Forest Associates who spoke on dynamic forces in airplanes, and the resistance to these forces by the materials used in construction. In the case of the dynamic resistance of materials, there is still a great lack of accurate information. Mr. De Forest went on to say: There has been much study applied to the fatigue testing of small samples of carefully prepared specimens, but very little to the controlled testing of finished parts and structures. Not only the dynamic properties of finished parts of normal materials are unknown, but the damage caused by what appear to be insignificant defects is seldom appreciated. The development of a test for such defects in steel parts has greatly helped in reducing certain types of failure.

The Magnaflux Test was then described as follows: When the magnetic flux in a substantially uniform field is interrupted by a sudden discontinuity, a small magnetic pole forms a leakage field over the defect. This field can be indicated by its attraction for finely divided iron particles. The most efficient form of iron powder for this purpose is made from slender chips of highly permeable, hydrogen reduced steel. These particles are rendered more visible by a coating of white pigment, which also serves to break up their magnetic continuity, and makes them more slippery.

A number of airplane parts, valve springs, forged fittings, tubing, gears, components of adjustable pitch hubs, etc., were used to illustrate different kinds of defects. The use of the test on valve springs was described as typical. In this case the dynamic load on the spring had been long suspected as being to blame for fatigue failure. The spring steel was also investigated, as were the methods of heat treatment; but an investigation of many failed springs invariably showed the presence of a longitudinal seam as the stress raiser, which greatly lowered the fatigue resistance of the failed section.

The samples and a salt shaker of the iron powder were passed around the audience while Mr. De Forest drew attention to the enormous reduction in dynamic resistance caused by such sharp notches as seams, hair cracks, grinding cracks, cold shuts, heat treating cracks and defective welds. While such defects have substantially no influence on static strength their effect on the fatigue resistance may lower the dynamic strength by 50 to 90 percent. Less pronounced damage is caused by improper design and workmanship at changes in section. Every engineer knows that generous fillets should be used to decrease stress concentration, but all too many engine and plane parts, while carefully made and of the highest grade materials, are limited by their design to less than half the strength to which their weight should entitle them.

AERODYNAMICS

Charles H. Chatfield, Director of Research, United Aircraft and Transport Corporation, dealt with experimental work on cowling and cooling radial air-cooled engines which had been done during the past two years by three of the subsidiaries of United Aircraft and Transport Corporation, and summarized briefly the paper on this subject by Messrs. Beisel, MacClain and Thomas which had been presented at the annual meeting of the Society of Automotive Engineers during the previous week.

CHARLES H. CHATFIELD

In this summary, it was pointed out that the earlier work, aimed at increasing the flow of air through the cowl over the engine cylinders, had generally resulted in only moderate improvements in cooling, coupled with substantial increases in engine drag. The second and successful phase of the development was directed toward limiting the quantity of air flowing under the cowl and compelling substantially all of it to pass over those parts of the cylinders which were not effectively cooled by the natural flow. This result was accomplished by the use of "close" or "pressure" baffles which closed the spaces between the cylinders. The air was thus forced to flow between the cylinder cooling fins and was effectively directed over the rear portions of the cylinders. With these baffles and an NACA cowl, the cooling in flight was often better than that with an engine having neither cowl nor baffles. The baffles, when used with properly designed cowling, generally gave a substantial improvement in airplane performance. The work on cowl shapes done in Hartford tended to confirm the original recommendations of the NACA and indicated that the nose of the ring cowl should have a smooth entry with a diameter about 80 percent of that of the engine, and that the skirt should fair approximately to a line joining the nose and shoulder cowls. Since any form of fixed cowl must be designed to give adequate cooling under the least favorable condition, such a cowl tends to give excessive cooling under more favorable conditions and does this at the cost of an unnecessarily large drag at top speed. This circumstance suggested work on a controllable cowl, and among several forms tried, that with a simple trailing edge flap has thus far been found most desirable. Such a cowl is so designed that, with the flap retracted, the drag is a minimum and the cooling just adequate for the most favorable condition, that is, for cruising in level flight. For the most severe cooling condition, which is ordinarily that of climb at best rate with propeller in low angle position, the flap is extended. In this position, the air flow is increased to an amount affording adequate cooling and this is accomplished with an increase in drag which causes only a very moderate decrease in rate of climb.

DR. TH. VON KÁRMÁN

Dr. Th. von Kármán of The California Institute of Technology discussed different aspects of the turbulence problem and some recent progress in our knowledge of the influence of turbulence on aerodynamical characteristics of flat plates, streamline bodies and airfoils.

He pointed out that the expression "turbulence" is often applied to phenomena which have little in common with turbulence as defined in scientific fluid mechanics. Vortex motion, for instance, is not necessarily turbulent motion. Turbulent flow is characterized by irregular fluctuations of the magnitude and direction of the velocity and by permanent interchange or mixing of the fluid particles between adjacent layers. The experimental investigation of turbulent flow consists of the measurement of air forces in flows with different degrees of turbulence and of direct records of the fluctuations, especially of those obtained by means of the hot wire anemometer.

The aeronautical engineer is concerned with the influence of turbulence on the skin friction of plates and streamline bodies, particularly for drag calculations and for extrapolation of wind tunnel measurements to full scale conditions. Theoretical work done by Dr. von Kármán in combination with experimental work in Pasadena, has enabled research men to predict the speed of airplanes from wind tunnel tests with an accuracy satisfactory for practical purposes. The influence of roughness is one of the important questions open for future research; a promising start has been made in the last few years.

The sudden drop in the drag of spheres at a certain critical Reynolds number has been revealed by measurements of Eiffel in the early years of wind tunnel research; Prandtl and his collaborators connected this phenomenon with the turbulence of the boundary layer; Dryden found the quantitative correlation between the critical Reynolds number and the magnitude of turbulent fluctuations. Recent investigations in Pasadena revealed that the stalling of airfoils can be correlated with the turbulence of the stream surrounding the airfoil, characterized by the critical Reynolds number of spheres and by the magnitude of fluctuations. This problem is of great importance for the prediction of maximum lift and minimum speed of airplanes. The critical Reynolds number of spheres in the free atmosphere was measured in Pasadena by suitably attaching the spheres to an airplane in free flight. The flight tests show a surprisingly lower degree of turbulence in the free atmosphere, even in rough weather conditions, than in any of the existing wind tunnels. This may be explained by the fact that rough air has a large scale turbulence of great intensity, but the fast small scale fluctuations, which probably influence the boundary layer, have a smaller magnitude in the free air than in the wind tunnel.

Dr. von Kármán believes that an understanding and a systematic investigation of the turbulence problem are necessary for rational use of wind tunnel tests, for successful solution of certain design problems, and for rational use of meteorological data and weather forecasts.

PROFESSOR ALEXANDER KLEMIN

Professor Alexander Klemin of New York University pointed out that for many years attention had been concentrated on the improvement of the landing speed, steepness of glide and landing run. Many devices such as slots and flaps are employed with success, and the flap has become deservedly popular in the United States. Devices for improvement in take-off and climb over an obstacle had not made equal progress. It was a great step forward to be able to make an emergency landing in a small

field, with surrounding obstacles, but it was equally desirable that take-off from such restricted territory should also be possible. The speaker undertook a brief examination of several devices.

The split flap when depressed reduced the take-off run, but the subsequent climb with flap depressed was poor. Therefore no direct improvement in clearing an obstacle could be expected from the split flap. The split flap could be made to improve take-off characteristics indirectly, if employed not to reduce the landing speed but to reduce the wing area (without reducing span). Such use of the split flap would improve steepness of climb, but lengthen the take-off run. The advantage to be gained was slight therefore.

Increase of wing area by chord extension improved the take-off run but decreased the steepness of climb. In this device also there were two mutually contradictory tendencies at work.

Increase of wing area by means of telescopic wings improved the take-off run, and also the span loading and steepness of climb. Hence telescopic wings were from an aerodynamic point of view very interesting in the take-off problem.

The Medvedeff monobiplane in which a biplane could be converted into a monoplane and *vice versa*, increased wing area and decreased equivalent span loading, so that the monobiplane was also theoretically a very promising device. Wind tunnel tests under the speaker's supervision had demonstrated aerodynamic values conclusively.

Tests by the speaker on a model of the Crouch-Bolas Dragonfly, where large diameter propellers placed wings provided with slots and flaps within the slip stream of the propeller had also indicated a very considerable improvement in take-off characteristics.

Application of the slipstream control to a variable incidence wing, while complicating matters, gave evidence of even more powerful effects.

The speaker concluded by saying that ten years ago lift increase devices had been regarded with suspicion. Devices for improving take-off might in time prove equally practicable and deserved full consideration by engineers.

DR. CLARK B. MILLIKAN

Dr. Clark B. Millikan of the California Institute of Technology prefaced his remarks by suggesting that two of the legitimate endeavors of a research institution were the investigation of new physical principles, and the analysis of known principles with the view of developing simple and general methods for their application by practical engineers. Dr. von Kármán had just discussed some investigations of the first type while the present speaker proposed to discuss very briefly some work in the second category which had recently been in progress at the Guggenheim Aeronautics Laboratory of the California Institute of Technology. In view of the briefness of the time available he would restrict himself to the single problem of airplane performance prediction.

An elaborate analysis by Dr. W. B. Oswald during his graduate study at the California Institute had led to a simple analytical treatment of the problem which had been published as a Technical Report by the National Advisory Committee for Aeronautics. This Report included charts by which the performance of an airplane with unsupercharged engine and fixed pitch metal propeller could very rapidly be determined when the values of certain basic parameters were given. These parameters included the normal engine characteristics, the weight and dimensions of the airplane and three aerodynamic parameters. The latter were:

(a) the maximum lift coefficient which determined the stalling speed,

(b) the equivalent parasite area or the product of the wing area and the value of the parasite drag coefficient at the high speed altitude of the plane, and

(c) the airplane efficiency factor, which gave essentially the variation of parasite drag coefficient with lift coefficient.

The purpose of wind tunnel tests, insofar as performance estimation was concerned, was to furnish the designer with numerical values for these three parameters. This, however, involved in general an extrapolation of the experimentally observed values to full scale, free flight conditions. The extrapolation of $C_{L_{max}}$ was known to be highly dependent on the Reynolds numbers and turbulence characteristics of the experimental and free flight conditions. In spite of extensive experimental and theoretical researches at the California Institute which appeared to have elucidated the physical aspects of the phenomenon for moderate and fairly large Reynolds numbers, the speaker expressed the opinion that the actual extrapolation to very large Reynolds numbers was still largely dependent on the judgment of the individual. Such judgment might be greatly assisted by the empirical data collected by Jacobs, Klein and others, but it was felt that there was still room for further research in this connection.

The speaker then described briefly a method which he had developed for extrapolating wind tunnel values of the equivalent parasite area to full scale conditions. This method employed the theory of turbulent skin friction given by von Kármán as well as experimental data obtained by testing the model at a series of Reynolds numbers. The results obtained were stated to have been highly satisfactory for those cases in which a comparison was available between the predicted value and that determined from flight tests on the full scale airplane.

With regard to the efficiency factor, the speaker expressed the opinion that the effects of turbulence and Reynolds number were relatively small, but that the influence of propeller slipstream might be of considerable importance. Experiments in hand at the California Institute for the investigation of this matter were mentioned.

The speaker stated that Oswald's method of analysis had proved to be extremely useful for research purposes because of the clear manner in which the effects of the various physical parameters were brought out by this method. When used in connection with aerodynamic data obtained as described above, it had also been extensively used by designing engineers as a routine tool for performance prediction. The extension of the method to include supercharged engines had already been made by Oswald

and reported in an Air Corps Information Circular. The further extension to continuously variable controllable pitch propellers was being actively investigated at the California Institute.

G. W. LEWIS

Mr. G. W. Lewis, Director of Aeronautical Research, of the National Advisory Committee for Aeronautics, discussed in general some of the more important investigations under way at the Committee's laboratory at Langley Field. He mentioned in particular some of the boundary layer control investigations and referred to two interesting applications of boundary layer control: (a) a streamline wire, where the drag of the wire was decreased by creating a turbulent flow at the center section, and (b) a high-lift device which depended upon the creation of a turbulent flow near the leading edge of the wing.

Mr. Lewis was of the opinion that the next marked improvement in the airplane would be the result of a better understanding of boundary layer control and its application to the lifting surfaces of aircraft.

Mr. Lewis then called upon Mr. Fred E. Weick, of the Committee's staff at Langley Field, to explain in some detail the results of an investigation of a means of obtaining lateral control by a spoiler type aileron.

FRED E. WEICK

Some of the high lift devices being investigated at the N.A.C.A. laboratories were described by Mr. Weick and are of interest following Dr. von Kármán's remarks on turbulence. The action of a fixed auxiliary airfoil ahead of a wing was discussed. The auxiliary airfoil stalls before the main wing and its turbulent wake in effect scours away the boundary layer over the main wing, delaying the stall and increasing the maximum lift. A few lateral control devices for use with full-span flaps were then described, particularly the retractible spoiler which projects from the upper surface of a wing, and which seemed very promising from the first wind tunnel tests. Flight tests, and later dynamic wind tunnel tests, however, showed that the spoilers had a lag or delayed action which ranged from about one-half second, if located near the leading edge, to zero if located at the trailing edge. Possible means of eliminating the lag are now being investigated.

PROFESSOR R. H. SMITH

Professor R. H. Smith of the Massachusetts Institute of Technology, the last to speak on aerodynamics, spoke briefly of the need for more information on the dynamics of unsteady flows which underlie such phenomena as wing and propeller flutter, tail buffeting, lateral control and burbling. He cited the particular need for a precise analysis of the phase and amplitude relationship between the momentary circulation around an oscillating wing at any given attitude in its cycle and the steady circulation around the wing when fixed at that attitude. He further pointed out that along with these relationships a satisfactory evaluation of certain rotary derivatives and a successful determination of the additional pressural forces which are associated in all unsteady flows about a body with the changing energy in the surrounding field must also be made before the complete differential equation of wing flutter can be set up. Among the other cases of unsteady flow to which he referred the most important one was burbling and its connection with lateral control. He mentioned briefly two studies which have recently been made on the mechanics of flow breakaway. One was an analytical study based on the theory of the laminar regime near the leading edge and hence concerned with a late stage of burbling. The other was an empirical or semi-empirical study based on experimental measurements in the turbulent regime over the after part of the wing and so is concerned with the earlier phases of burbling. The first study was made at California Institute of Technology; the second at Massachusetts Institute of Technology. While both studies are advances, the mechanics of burbling are still largely unknown.

FUELS

The discussion of fuels was led by Major Edwin E. Aldrin, President of the Stanavo Specification Board. He gave a short summary of the present status of aircraft fuels and introduced Mr. deFlorez.

LUIS DEFLOREZ

Luis deFlorez, Consulting Engineer, New York City, outlined some of the problems confronting the manufacturer of engine fuels. He briefly reviewed the general methods of producing gasoline and other fuels and their commercial requirements. He drew attention to the great importance of standardizing petroleum products and eliminating the duplication of effort and increased cost attendant upon the supplying of several grades of fuel. In connection with future development in this field, he spoke as follows:

"In discussing fuels for internal combustion engines, we may sometimes lose sight of the fact that the term *fuel* covers a wide range of substances which may be used in such engines, depending on the mechanical means available to supply it to the cylinders with the requisite amount of oxygen. At the present time engine fuel has become almost synonomous with the petroleum distillate commercially known as gasoline, which has for its basic characteristic a relatively low boiling range permitting it to be mixed with air, vaporized and distributed to the engine cylinders in gaseous form. We have been only to a lesser extent interested in the relatively non-volatile distillates which have to be distributed to the cylinders by other means, such as injection. Each type of fuel presents certain advantages and disadvantages which must be clearly kept in mind. The chief advantage of vaporizing fuel lies in the relatively easy mechanical means of distribution to the cylinders, while its disadvantages are its tendency to detonate at high compressions and its fire hazard. The non-vaporizing fuel's almost only disadvantage lies in the mechanical difficulty of handling it in the engine.

"Originally, the term *gasoline* was used to designate a distillate which vaporized reasonably well in a carbureting system. Over a period of years it has become more accurately defined and restricted because of the requirements of the more complex engines, until today it has a host of requirements, both physical and chemical, chief among

which are its boiling range and anti-detonating properties. We find today that the boiling range of automobile gasoline lies approximately between 100 and 400°F, while that of aviation gasoline lies between 100 and 300°F. The difference is largely due to the greater difficulty in distribution in manifolds in connection with the aviation engines, and the wide variations of temperature and pressure under which such engines must operate.

"The problem of producing suitable gasoline for automobiles is obviously much less difficult than that of furnishing a suitable one for air craft, since the problems of weight and space requirements in the automobile engine are relatively unimportant, and the necessity for high compressions does not exist. It is true that intensive advertising has created a public demand for the higher compression fuels for automobiles which is now being supplied at the expense of conservation and the public's pocket book. There is no question, however, that a saner point of view will eventually assert itself which will end the race for increasing anti-knock values in commercial automobile fuels and leave a reasonable requirement as a standard.

"The matter of standardizing gasoline is obviously of immense importance in view of the distribution problems and the high cost of handling several grades. It would seem probable that the future will see one grade of gasoline which will fit all motor cars and all pocket books and that engines will be more and more designed with this end in view. There certainly appears to be much room for improvement in the design of combustion chambers, timing, cooling, etc., which, if properly recognized, will bring about better performance without recourse to excessive fuel requirements.

"Although the problem of producing one grade of gasoline for air craft engines is not so pressing at this time, due to the relatively small amount of fuel required by the air craft industry, it undoubtedly will become increasingly important. Admittedly, the matter of boiling range and anti-knock properties have a far greater importance in air craft fuel and concessions must be made to permit such engines to operate over a wide range of atmospheric temperatures and pressures and to permit reduction in weight and space to a minimum. It should be borne in mind, however, that as we decrease the boiling range we reduce the amount of gasoline which can be made available and as we increase the anti-detonating properties we multiply the difficulties and cost of producing such fuels out of proportion to the improvement obtained. At present the boiling range of aviation gasoline is of the order of 200°F with the anti-knock values of the order of 80 octane for commercial fuels. A decrease in boiling range does not appear at this time to present any particular advantage, while an increase in octane values, although possibly advantageous in high performance engines, will have the effect of greatly increasing manufacturing costs.

"Of course it may be possible to make specialized fuels with definite chemical properties using petroleum or coal tar as a base or by adding chemicals and no one questions their value for military purposes. If, however, we are to rely on the petroleum industry to supply a standardized aviation fuel in large quantities to be available throughout the country at a reasonable cost, it would certainly seem essential to lay increasing stress on the development of engines capable of utilizing to better advantage fuels which can normally be produced by the industry.

"Progress toward lighter and more compact aircraft power plants is undoubtedly dependent on the possibility of satisfactorily obtaining higher mean effective pressures but it does not necessarily depend on obtaining such pressures with a carbureting system. It would certainly seem proper to consider at this time whether we are not reaching a point beyond which such a fuel system is undesirable. Fuel injection, for instance, may well present a better approach to the high performance power plant in spite of its present mechanical difficulties. In any case it would permit far greater latitude in the choice of engine fuels, since it offers the possibility of accurate and positive distribution of fuel independent of atmospheric conditions, as well as the possibility of progressive burning which would relieve the requirements for anti-knock properties. The economic and technical limitations to which aviation gasoline is subject are beginning to be felt which indicates the necessity of widening the scope of research possibly to include less conventional design and, in any event, to proceed along lines which will place less reliance on highly specialized fuels."

Dr. Graham Edgar

In discussing aircraft fuel, Dr. Graham Edgar, Director of Research of the Ethyl Gasoline Corporation, brought up the rather interesting problem as to the proportion of the increase in aircraft performance in the last six years which was due to design and the proportion which was due to improvements in fuel. Six years ago a considerable proportion of the aviation gasoline sold in the United States had an octane number not higher than 50. There had been considerable reference to the remarkable performance of the Douglas plane. It would be interesting to know how much the performance would be cut down if only 50 octane number gasoline were available. There appeared to be no definite data on which the calculation could be made, but it would seem quite probable that the Douglas would not be able to get off the ground with such fuel. Dr. Edgar said that he raised the point merely because there was some tendency in aviation circles to attribute the remarkable increases in performance in the last few years almost entirely to design factors without realizing what a very important part improvements in anti-knock values of fuels had contributed to the problem.

Power Plants and Instruments

The discussion of Power Plants and Instruments was led by Mr. Charles L. Lawrance, President and Chief Engineer of the Lawrance Engineering and Research Corporation. He introduced Mr. George J. Mead, of the United Aircraft and Transport Corporation, who made a plea for the presentation of the results of research by the aircraft industry. Mr. Lawrance then introduced Mr. Nutt.

ARTHUR NUTT

Arthur Nutt, Vice-President, Wright Aeronautical Corporation reviewed the present status of the aircraft engine. At the present time approximately 95 percent of the aircraft engines in production are of the single row radial air cooled type. The largest percentage of these engines have nine cylinders although there are numerous five and seven cylinder engines still being sold. The balance of the engines are double row radial air cooled or liquid cooled engines. These engines may be divided into three groups of power classifications:

(1) Single row—750 to 800 hp.
450 to 550 hp.
350 to 250 hp.
250 to 100 hp.

(2) Two row—800 to 1000 hp.
600 to 750 hp.

(3) Liquid cooled engines—800 to 1000 hp.
675 to 750 hp.

The single row engine has held its supremacy in the field on account of its very light weight, economy of manufacture and easy maintenance. In the higher powers the engine is not as smooth as some of the other types but appears to be satisfactory if properly mounted. Improvement in smoothness can be obtained by going to higher speeds.

The two row radial air cooled engine has a much smaller diameter for the same horsepower and very much better vision in the single seater airplane. The engine is very smooth but is more expensive to build and maintain. The frontal area of engines of this horsepower is not as important in the two engine large airplane on account of the fact that the engine is a small percentage of the total drag. However, in the single seater, or small ship, as stated above, the vision is important and the frontal area becomes very important.

Liquid cooled engines are confined to the higher power on account of the fact that they are penalized with the extra weight of radiator and coolant liquid. The valve gear on the liquid cooled engines in production today is fully lubricated and also is operated with overhead camshafts. Such a valve gear arrangement makes engine operation at high speed easier.

Mr. Nutt further stated that there appears to be a general trend toward the use of liquid cooled engines in the higher power for several reasons. As the power of engines increases, both the weight and bulk must be greater and it is possible with the liquid cooled engine to build a certain displacement in a smaller space. The only serious disadvantage in the liquid cooled engine is the additional weight for short airplane flights. For long flights on account of the better fuel economy, which seems to be possible with the liquid cooled engines, the weight factor is overcome in a few hours of flight. It is possible also, as pointed out by Mr. Nutt, to cool very highly supercharged engines at high altitude when using liquid cooling. It was a well-known fact that the highly supercharged air cooled engine reaches its maximum cylinder temperatures close to the critical altitude of the ship, giving as an example—an engine supercharged to 10,000 feet probably reaches its maximum cylinder temperatures somewhere in the neighborhood of 10,000 to 12,000 feet altitude. Whether it is possible to cool this engine at 25,000 feet altitude with sea level horsepower is not definitely known. With the steady improvement in cooling of air cooled engines and the use of gasoline injection into cylinders, which makes possible the use of inter-coolers, it is not considered impossible to cool the large air cooled engines at high altitude. This development has not been completed and until it is completed the liquid cooled engine has a field of use in military aircraft at high altitude using various forms of supercharging such as the two-speed, two-stage or exhaust turbo superchargers which will permit take off and fast climb without sacrificing too much power at sea level. The speaker indicated that there seemed to be some trend toward two-cycle engines and sleeve valve engines, the latter design having been brought to a very successful beginning by Mr. Fedden of the Bristol Aeroplane Company in England.

Mr. Nutt further said that the Diesel engine in this country has not received much attention recently but, with the increased interest in trans-Atlantic operations, he velieved it possible that the Diesel would be revived during the next five years.

ELMER A. SPERRY, JR.

Taking "Instruments" as his subject Elmer A. Sperry, Jr., Consulting Engineer, Sperry Products Corporation, said that during 1933 there had not been any great advance in the engine instruments or electrical group, but that there had been some new development in the flight instrument group. Since the introduction a few years ago of the two latest instruments in the flight group, namely, the Directional Gyro and the Gyro Horizon, it had been found possible to greatly increase the usefulness of these instruments. Although the instruments comprising the flight group become very important when the necessity arises for flying "blind," during periods of good visibility the pilot pays practically no attention to them. There is good visibility during a large percentage of the time, hence the flight instruments are in actual use only a small part of the total flying hours. Since, when necessary, the pilot is able to fly the airplane by these instruments, the next logical step is to make the instruments fly the airplane. Then these instruments will be of use practically all of the time and the pilot will be relieved of the arduous task of continually manipulating the controls, which will permit him to give closer consideration to the air conditions through which he is navigating and to operation of the radio, etc., all of which lead to greater comfort and safety of flight. This has now been accomplished by a new arrangement of the airplane automatic control. This arrangement makes it possible for these two gyro instruments to operate servo-motors for moving the controls, at the same time confining them to a unit small enough to be mounted in their usual instrument board location. The new Douglas transport plane of Transcontinental and Western Air, Inc. has been equipped with this automatic pilot and has undergone a series of extensive tests which have been very satisfactory. The T. and W. A. Company is planning to make this pilot standard equipment on their new Douglas transports.

The Annual Dinner

At the Dinner, members of the Institute and guests were privileged to hear from a number of distinguished pioneers in the arts of aviation, who related both interesting and amusing experiences. Frank T. Coffyn spoke of teaching the early pilots, such as Norman Prince, Starling Burgess, Thomas Hitchcock, and Lieutenant (now General) Benjamin Foulois. Cross-country flying in those days meant hops of twenty to thirty miles, and the Collier-Wright plane had to make an endurance record of only 1½ hours for its official acceptance by the Signal Corps. Beckwith Havens made the curious observation that the early ships had no inherent stability in any direction, no instruments or gauges, yet students were put in a ship and expected to fly! Now that ships practically fly themselves, young men receive ten hours dual and fifty hours solo instruction before they can fly. Dr. A. F. Zahm, unable to be present at the dinner, has given the Institute, in a letter, some interesting views on early history, dealing briefly with the work of the Wrights, Langley, Curtiss, Ader, and Goupil. Dr. Zahm is, of course, an outstanding authority on the history of aviation.

Captain John H. Towers opened his remarks by reading a letter from the Navy Department written in the Autumn of 1910, which letter was a reply to his request to be detailed to learn to fly. The reply stated, in substance, that if and when the Navy Department ever considered aviation of use to the Navy, his request would be considered. He related how, during the following Spring, an appropiation of $25,000 was made by Congress for Naval aviation, three planes were ordered and, as part of the contracts, three Naval officers were to be taught to fly. The three were Rodgers, Ellyson and himself. Both Rodgers and Ellyson later met their deaths in aviation accidents. He described the "teach yourself" method of instruction then used in the Curtiss School, and many of the hazardous, yet amusing, experiences in mastering control of "Lizzie," the famous single-seat, pusher type, 30 horsepower training plane, which, beside the planes of today, would resemble the "Toonerville Trolley."

While the two Curtiss planes were being manufactured from plans drawn on the walls of the shop in free hand by Glenn Curtiss, a new employee, in cleaning up the place one Saturday afternoon, white-washed the whole place. No plans were left and nobody, not even excepting Glenn Curtiss, could reproduce them. A delay was requested of the Navy Department on grounds of "minor shop difficulties" and finally Curtiss drew more and manufacture proceeded.

Captain Towers related a number of incidents of early Naval flying, principally to show the almost absolute lack of knowledge then existing about dynamics, then closed his remarks by briefly summarizing Naval aviation of today to show how, in a span of a little over twenty-two years, it had grown from nothing to a powerful and absolutely vital component of the Fleet.

As a pioneer in Aeronautical Engineering education Dr J. C. Hunsaker described his early days at M.I.T. when, as a graduate student of Naval Architecture, he was given the job of finding out the engineering basis for aircraft design. He visited the pioneers of 1911–12 only to marvel at the ingenuity of the inventors and the courage of the pilots of that day. The engineering basis was unknown here and the most elementary facts of strength and stability had yet to be discovered.

It was his opinion that while both the airplane and the seaplane, as inventions, were American contributions, the fundamentals of aeronautical engineering were European in origin. He finally went, in 1913, to Mr. Eiffel's laboratory in Paris to learn the technique and theory of wind tunnel model experimentation. There he was taken on as an assistant and most kindly instructed. At a meeting where the Air Attaché of the French Republic was present, he wished to acknowledge his debt to Mr. Eiffel and the other French pioneers in aerodynamic science.

In that same year, 1913, he spent several months as an assistant at Teddington, in England through the kindness of Sir Richard Glazebrook. Here he received instruction in wind tunnel technique at the hands of Dr. Stanton and Dr. Bairstow and in particular in the theory of dynamic stability of airplanes. The British research workers should have full credit for first developing an adequate treatment of this vital problem of stability. In the presence of the British Air Attaché, Dr. Hunsaker wished to acknowledge his debt to the enthusiastic group of pre-war aerodynamic pioneers at Teddington and Farnborough.

American aeronautical engineering really dates from the establishment of the graduate courses at M.I.T. in 1914 with British and French laboratory equipment and technique.

The speaker sketched the somewhat irregular academic routine of the first group of students, A. Klemin, V. E. Clark, D. W. Douglas, T. Huff, R. D. Weyerbacher, B. Q. Jones, H. W. Harms, and the visiting experts, A. F. Zahm, G. Curtiss, W. S. Burgess, F. H. Russell, "Captain Tom" Baldwin, A. V. De Forest and L. deFlorez.

Mr. Glenn L. Martin related some of the difficulties in manufacturing and amusing experiences in flying early airplanes. Mr. R. A. D. McCurdy, the earliest living pilot except Orville Wright, told of the difficulties of the pioneer airmen and gave an amusing account of his flight to Cuba for a $10,000 prize which disappeared. Dr. Frank B. Jewett, President of the Bell Telephone Laboratories, spoke on *Pioneering in Aircraft Telephony*. He told of the early experiences with incredulous Army officers, particularly at one of the tests at Dayton, when one of the pilots, while in the air, expressed himself freely over radio about high ranking officers. Dr. Th. von Kármán spoke on his early experiments with helicopters. Vilhjalmur Stefansson told of the part aviation had taken in the exploration of the Arctic.

Annual Meeting

THE Second Annual Meeting of the Institute of the Aeronautical Sciences, Inc., was held in the Physics Building at Columbia University, New York City, on January 31, 1934. Dr. J. C. Hunsaker, President of the Institute, presided over the meeting and Major Lester D. Gardner acted as Secretary.

After the usual routine matters had been reported, the President read his Annual Report.

The President's Annual Report

LAST year when the Founders of the Institute met and held such a successful meeting, the membership vested plenary powers in the Officers and Council. Your President now gives you a report of the use that has been made of this authority.

The growth of membership and activities during this year has exceeded our expectations. We said at the last meeting that we believed that the Institute would eventually reach a status which would correspond to that occupied by similar societies abroad. I think that I am not exaggerating when I state that the Institute has in one year approximated the desired position.

The publication of our *Proceedings* and its wide distribution made our aims, activities, and membership known in the leading aeronautical centers of the world, and the election of so many distinguished foreign aeronautical specialists and their acceptance of membership has enhanced our prestige. Although we have been careful to maintain our standards of qualifications for membership, the number of members has nearly doubled in the past year.

The recent opening of the Skyport should help the Institute greatly. It has given us a centrally located headquarters and clubroom where we can conduct the work of the Institute and where members may meet socially. We are under great obligation to the generous donor who made the Skyport available. To Grover Loening, who provided the furnishings and decorations, we are also very grateful. To R. H. Fleet, T. P. Wright, George Mead, Glenn L. Martin, Paul Litchfield, Luis deFlorez, and Lester Gardner, all of whom added to Mr. Loening's original equipment, I express public appreciation.

At the Founders' Meeting, last year, the publication of a scientific quarterly was advocated. You have now received copies of the first issue of the *Journal of the Aeronautical Sciences*. I agreed to edit the first issue and Lester Gardner agreed to secure advertising to help pay for it. Our contributors wrote professional articles to make it worth printing. The advertising paid for the first issue, but we have a serious problem in regard to the future which we must discuss during the meeting.

At the Founders' Meeting last year the Council was given nearly autocratic power. The Council appreciated this confidence, but felt that, while executive and initiating authority must be centralized, matters concerning the policy of the Institute should be considered by a larger group. Instead of enlarging the Council, which is a difficult process, it has, by amending the By-Laws, created an Advisory Board which will guide it on matters of policy. The section added to the By-Laws reads as follows:

"An Advisory Board consisting of twenty members of the Institute shall be elected at each Annual Meeting. The members of the Advisory Board shall have access to the minutes of the Council and may be polled by mail vote on questions of policy affecting the Institute. The Advisory Board may advise the Council on its own initiative and shall advise the Council on matters submitted to it by the Council. The opinions of the Advisory Board on matters of policy shall be matters of record and shall be incorporated in the President's annual report."

Your Council has elected the first group of Fellows. Believing that the election of Fellows should, in future, be vested in a wider group, you will be asked to consider transferring this responsibility from the Council to the Fellows themselves. Many members have been nominated as Fellows, and the Council could have elected forty American Fellows and thirty foreign Fellows, but preferred to leave the election of some of these, as well as the extra twenty to be elected in 1934, to the group to which you delegate that responsibility at this meeting. I hope that this spreading of authority will indicate to the members that the Officers and Council are appreciative of the powers granted for the first year but do not wish to have them made permanent.

The response to my letter regarding the payment of dues for this year has been gratifying. Nearly seventy-five percent of the membership have sent checks. We have sent a copy of the *Journal* to all members, but cannot continue to send it to those whose dues are in arrears.

I wish to add a personal word of appreciation of the cooperation and unselfish labors of many of our members in connection with organizing and editing the *Journal*. First, I must thank my friends, the contributors who have really shown what American aeronautical science is dealing with, and by contributors I do not mean only those whose papers have appeared in the first issue, but especially those whose papers were held for the second issue, or held up for argument with the editor and for necessary condensation. It is a thankless task to send a fine professional paper and then be asked by the editors to cut it to half size without leaving anything out. The success of the *Journal* is assured from the editorial side by the standard set by our own members. However, our funds are too slight to maintain the publication unless it can win by its own merits a wide circle of non-member subscribers. With your continued support, I am sure, it can do this.

In conclusion, I wish to point out that we should list as the foremost of our benefactors, Lester Gardner, who has contributed a year and a half of his full time services to the organization and sound development of the Institute. The

most serious problem for the coming year is: "How can we get along without his management?"

After the President's Report had been approved, Mr. Charles L. Lawrance read the report of the Treasurer.

The Treasurer's Report

The work of the Treasurer of the Institute is largely supervisory, according to the By-Laws. I have had the books audited by my auditor and present herewith the Annual Statement as of September 30, 1933, as required by the By-Laws.

Annual Balance Sheet

Assets	
Cash in Bank	$ 705.01
Accounts Receivable—Dues	140.00
Accounts Receivable—Proceedings	.80
Office Equipment	161.11
Printed Matter	70.00
"Proceedings"—400 copies	100.00
Total Assets	$1,176.92
Liabilities	
Accounts Payable	$
Net Worth	1,176.92
Total Liabilities	$1,176.92

Operating Statement

Receipts	
Dues Received to 9/30/33	$2,434.00
Initiation Fees to 9/30/33	51.00
Receipts from "Proceedings"	955.00
Sales of Annual Meeting Tickets	132.00
Total Receipts to 9/30/33	$3,572.00
Cash	
Cash in Bank	$ 705.01
Disbursements	
Organization Expense	$ 58.23
Collection and Exchange	5.88
Cost of Annual Meeting	215.25
Miscellaneous Expense	371.96
New Member Expense	90.05
Office Equipment	161.11
Postage	258.96
Printing	290.95
Stationery	151.69
Salaries	255.00
Cost of "Proceedings" 1933	1,007.91
Total Disbursements	$2,866.99
Total Disbursements and Cash in Bank	$3,572.00

So that members will have a more recent statement, I will give them the more important figures from the statement of December 31, 1933.

Cash on hand	$ 875.36
Dues paid	1,444.00
Dues payable	1,141.00
Net worth	5,449.09

The latter figure includes prepaid rent, donations from members for the Skyport and inventory. The net worth of the Institute has increased over $4000 since October 1st.

While the above figures indicate very careful management on the part of the Secretary, it should not create a feeling of complacency regarding the future. We can no longer expect our Secretary to give all his time to the work of the Institute as he has for sixteen months without compensation. We must expect to have an executive secretary on a regular salary. The expenses of publishing the *Journal* must be carefully planned. With an income from dues of only $2500 a year some other source of revenue must be secured. This has received careful consideration by your Council and you will hear more about it from others.

After the Treasurer's Report had been approved, Major Lester D. Gardner read the report of the Secretary.

The Secretary's Report

The Secretary, according to the By-Laws, is practically the general manager of the Institute and therefore his report will be confined to the management problems of our organization.

Membership. I present herewith the annual membership statement.

Membership on January 1, 1933	408
New members elected during 1933	253
Resignations	4
Deceased	2
Total membership on January 1, 1934	655

The division of the membership by classes as of January 1, 1934 is as follows:

Honorary Fellows	2
Scientific Members	195
Engineering Members	270
Pilot Members	54
Industrial Members	124
Technical Members	10
Total	655

Of the above, *132* are Foreign Members.

For the last six months, there has been no special effort made to secure new members. The Council felt that it would be better for the Institute to grow naturally than by forcing.

Finance. The Institute has been able to function on its present income only by the most careful planning and anticipating extraordinary expenditures.

Last year, $900 in advertising was secured to pay for the printing and distribution of the 1933 *Proceedings and Membership List.* This very important publication could not have been published without the generous advertising support of companies in the aeronautical industry.

Similarly, when the Council considered the publication of the *Journal of the Aeronautical Sciences*, the companies

in the industry were asked to give advertising support. The advertising amounted to about $1500, which was none too much to publish 2300 copies of the *Journal* and distribute them to the leaders in aeronautics throughout the world. Members should bear in mind, in the discussion regarding the future of the *Journal*, that all the editorial contributions were made without payment, the advertising was secured without expense, and the expense of securing subscriptions had to be borne by the first issue. In the future, this will not be possible, as members cannot be expected to do the amount of highly specialized work that is necessary. It must be done on a business basis. This is one of the most important matters for the membership to consider.

While the Institute has been very fortunate in having received a donation of a year's rent and most generous donations toward decorations, furnishings, and equipment, the membership should consider the obligation involved in upkeep and maintenance. Your Secretary wishes to express his appreciation for the extreme freedom given to him by Mr. Loening in incurring obligations far beyond the ordinary necessities. After he had laid an excellent foundation, it was found that other equipment would be useful. Your Secretary did not hesitate to purchase what was needed and send the bills to those members mentioned by the President.

Your Secretary has been asked to give some ideas of the possible scope of the activities of the Institute that should be considered in setting up a budget for the next year. These are based on the activities of similar organizations in other countries.

Headquarters. The maintenance of the Skyport as a clubroom and office for the Institute is not only necessary for the functioning of the Institute, but provides members with a convenient meeting place and attractive room to entertain guests.

Library. A start has been made by gifts of a few hundred volumes. As there are general aeronautical libraries available nearby, it should be the purpose of the Library of the Institute to specialize in securing books, pamphlets, and periodicals of a scientific and engineering character. This part of the Institute work is of the greatest importance as out of it should grow a digesting and reviewing service, such as all other branches of science maintain. This is one of the activities which would justify support by the aeronautical industry and later an endowment from a benefactor. Your Secretary can visualize a donor, in the future, erecting a memorial library building which would be the center from which would radiate aeronautical information in the form of reviews, digests, and indexes.

Meetings. The Institute should hold meetings at which the latest developments in the aeronautical sciences are disclosed and discussed. Distinguished speakers are available and their papers would appear in the *Journal of the Aeronautical Sciences*. In fact, one of the main purposes of the meetings of societies is to secure editorial material at no expense for their publications.

Publications. The principal function of any scientific body is to disseminate knowledge through official publications, reprints, proceedings, indexes and bulletins. Every society that I know has one or more publications which it distributes to its members and others interested in the latest developments in its field. Gradually, as a field expands, the publications are subdivided, some scientific societies having different publications which deal with the commercial, theoretical, and digesting branches of their work. An Annual giving lists of members, constitution, By-Laws, etc., should be available to members. Supplementing this is a large amount of printed matter which is necessary for any active society.

Prizes and Medals. In order to stimulate the full disclosure of new and valuable aeronautical scientific work, prizes should be given for pre-eminent contributions to knowledge. Medals, with or without cash awards, should be presented annually. These will not only be an incentive to effort, but will bring to the Institute the more important contributions to aeronautical knowledge.

Sponsoring of Scientific Projects. The Institute can, after investigation, give approval to projects which aim to advance the science of aeronautics. Donors to such projects could in this way be assured that the effort is a real contribution to knowledge.

Publicity. The Institute can become the logical medium for the announcement of new developments in the aeronautical sciences. By giving such work publicity, it will keep the workers in the field abreast of the most advanced work being done.

As the Institute has had no staff until last November, and since then only the most limited assistance, I hope members will overlook any shortcomings of your Secretary's work. He has tried to keep the affairs of the Institute in order, but they have now grown to an extent where they require full time supervision and direction. While this is a matter which the Council will have to settle finally, the membership should know that it is perhaps the most important decision to be made regarding the future activities of the Institute.

To the members of the Council, who were really the founders of the Institute, your Secretary wishes to express his appreciation for their cooperation and assistance during the trying formative period. For the kind words of approval from individual members he is deeply grateful. He hopes that the combined efforts of the Council and members will make the Institute one of the most effective agencies for the advancement of aeronautics in the world.

After the Secretary's Report had been approved, the Constitution of the Institute was amended so that officers of the Institute could be elected from other than members of the Council.

The election of two Honorary Fellows was announced:

Dr. Ludwig Prandtl, Professor at Göttingen University, Director of the Kaiser Wilhelm Institute for Fluid Motion Research—*In recognition of his creative work in bringing*

classical hydrodynamics to a useful application as an aeronautical science and in particular for his development of the fruitful conception of induced resistance and boundary layer in aerodynamics.

Dr. Jerome Clarke Hunsaker, Head of the Department of Mechanical Engineering and Professor in charge of Aeronautical Engineering, Massachusetts Institute of Technology; President, Institute of the Aeronautical Sciences—*For the application of naval architecture to aircraft design and for contributions to aeronautical engineering education.*

The President stated that the Council had decided that it would neither nominate nor vote on any officer or member of the Council for the grade of Fellow, with the exception of Dr. Ames.

The President then announced that the following members had been elected Fellows of the Institute:

Joseph Sweetman Ames, Ph.D.—*For the organization and wise direction of research of the National Advisory Committee for Aeronautics.*

Karl Arnstein, Dr. Tech. Sci.—*For contributions to the development of airships, both in Germany and in the United States.*

Lyman James Briggs, Ph.D.—*For the application of physics in aerodynamical research.*

Charles Hugh Chatfield, M. Sc.—*For contributions to aeronautical education and research.*

Lieut. Comdr. (U.S.N.) Walter Stuart Diehl, B.Sc.—*For the application of the results of aerodynamic research to design problems.*

Donald Wills Douglas, B.Sc.—*For design and construction of many airplanes of outstanding originality and efficiency.*

Hugh Latimer Dryden, Ph.D.—*For his contributions to fundamental knowledge of aerodynamics.*

C. L. Egtvedt—*For his valuable contributions to the development of military and commercial aircraft.*

Alexander Klemin, M.Sc.—*For his services to aeronautical education.*

Isaac Machlin Laddon, B.Sc.—*For contributions to aeronautical structures and aircraft design.*

George William Lewis, M.M.E.—*For valuable services to aeronautics in the direction of fundamental research in many fields.*

Glenn L. Martin, Hon. D.Sc.—*For advances in aircraft construction and the development of aircraft of notable performance.*

Lessiter C. Milburn, B.Sc.—*For the design and development of many types of aircraft of high efficiency.*

Max Michael Munk, Ph.D.—*For contributions to aerodynamic theory and for improvements in the means of experimental investigation.*

John Knudsen Northrop—*For advances in the design and construction of metal airplanes.*

Arthur Nutt, B.Sci.—*For the design and development of aircraft power plants of many types.*

Sylvanus Albert Reed, Ph.D.—*For contributions to the development of metal propellers.*

Captain (U.S.N. Ret.) Holden Chester Richardson, M.Sc.—*For notable improvements in seaplanes and flying boats.*

Igor I. Sikorsky—*For contributions to airplane design and construction and for the development of fundamentally new features in design.*

Charles Fayette Taylor, M.E.—*For the dissemination of knowledge regarding aircraft power plants.*

Theodor von Karman, Dr. Ing.—*For notable contributions to theoretical aerodynamics.*

Fred Ernest Weick, B.Sc.—*For research resulting in improvement of the design of aircraft propellers.*

Albert Francis Zahm, Ph.D.—*For pioneer contributions to aerodynamics and for wise counsel to two generations of aeronautical engineers.*

The Nominating Committee reported the following nominations:

For the Council for three years: Major E. E. Aldrin, Dr. James H. Kimball, Arthur Nutt, Elmer A. Sperry, Jr.

For the Advisory Board: L. J. Briggs, C. H. Chatfield, J. H. Doolittle, C. L. Egtvedt, W. R. Gregg, Frank M. Hawks, L. M. Hull, J. H. Kindelberger, Alexander Klemin, I. M. Laddon, G. W. Lewis, Glenn L. Martin, W. H. Miller, C. B. Millikan, J. K. Northrop, A. A. Priester, H. J. E. Reid, L. D. Seymour.

The meeting voted to elect to the Council and the Advisory Board the names presented by the Nominating Committee.

During a recess of five minutes, the Council met and elected officers of the Institute for the ensuing year:

President	Charles L. Lawrance
Vice-Presidents	Donald W. Douglas
	Lessiter C. Milburn
Treasurer	Major E. E. Aldrin
Secretary	Major Lester D. Gardner

The last-named officer was selected at a subsequent meeting of the Council.

The following members were elected to serve on the Nominating Committee for the ensuing year: George W. Lewis, Chairman, Alexander Klemin, Glenn L. Martin, Holden C. Richardson, Ralph H. Upson.

After a general discussion regarding membership and the *Journal*, the retiring President, Dr. Hunsaker, presented the newly elected President, Mr. Lawrance.

The meeting gave a rising vote of thanks to Dr. Hunsaker for the able manner in which he had served the Institute since its foundation. Earlier, the meeting had given a similar vote of thanks to Major Gardner.

President Lawrance expressed his appreciation of the honor conferred upon him by his election as President, and said he hoped that the Institute would continue to grow and be successful during the coming year. The meeting then adjourned.

Necrology

Major General (U.S.A. Ret.) George Owen Squier, a Scientific Member of the I. Ae. S., died in Washington on March 24, 1934. He was born March 21, 1865, graduated from West Point in 1887 and received the degree of Ph.D. from Johns Hopkins University in 1903. His Army career was mainly spent in the Signal Corps of which he became Chief Signal Officer in 1917. As such he was in command of the aerial forces of the Army. He specialized in electrical communications and developed the system known as "wired wireless." As the result of his researches he secured patents in many fields. He received many scientific honors and was a member of numerous scientific societies. General Squier retired in 1923. In January he sent a telegram expressing his regret in not being able to attend the Annual Meeting of the Institute and made the following suggestion:

"Aeronautics is now ready for a super-Eiffel Tower at Langley Field for research and world broadcast on a special U. S. short wave-length. This new structure must combine sound, light and meteorology into a balanced unit of beautiful art."

Major William Joseph Hammer, a Scientific Member of the I. Ae. S., died in New York City on March 24, 1934. He was born at Cressona, Pennsylvania, February 20, 1858. He was one of the early associates of Thomas A. Edison, becoming his assistant in 1879. He was later chief engineer of several of the Edison companies and represented Mr. Edison at the Crystal Palace Exposition in 1882 and the Paris Exposition in 1889. He was president of the Edison Pioneers in 1920.

His aeronautical interest commenced in 1889 when he made a balloon flight from Paris. He was well acquainted with Langley and later, when the Wright brothers flew, he built hangars on Governor's Island, New York, and made contracts with Wilbur Wright and Glenn Curtiss to fly. He published, in 1911, the first complete aeronautical chronology. Later he testified as an expert for the Wright brothers in their airplane litigation.

His interest in aeronautics continued until his death. He was honored by many scientific organizations with medals and fellowships and by the French Government with the Legion of Honor.

Thorp Hiscock, an Engineering Member of the I. Ae. S., died in Chicago on March 16, 1934. He was forty-two years old. At the time of his death he was Vice-President in charge of Technical Development of United Air Lines. He graduated from Cornell University and during the War was Chief Instructor at Ellington Field. He specialized in radio communications for air transport.

Bibliography on Skin Friction and Boundary Flow

The Library of Congress has published a comprehensive list of references to surface velocity and friction of fluids in steady motion along solid boundaries, by A. F. Zahm and C. A. Ross. The compilation includes papers earlier than 1933 with an appendix giving the principal contributions in 1933. It may be unnecessary to state that the references apply to both air and water and deal with both theory and experiment. In making this bibliography available to scholars, the Library of Congress is encouraging the development of the aeronautical sciences.

Donors

The Institute expresses its appreciation for the following gifts:

Mr. Frank Curtiss—*Air Pioneering in the Arctic* by Amundsen and Ellsworth.

Mr. G. R. Wadsworth—Seven volumes, *N. A. C. A. Annual Reports.*

Mr. G. W. Lewis—Eleven volumes, *N. A. C. A. Annual Reports.*

General G. A. Crocco—*Elementi di Aviazione* and *Problemi Aeronautici.*

Mr. Lorillard Spencer—Miscellaneous books.

Dr. Max M. Munk—*Principles of Aerodynamics* and *Fluid Dynamics for Aircraft Designers.*

Eastman Kodak Company—Photographic mural of New York City.

Sperry Gyroscope Company—Model gyroscope.